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A COMPENDIUM OF PAPERS

SUBMITTED TO THE

SUBCOMMITTEE ON PRIORITIES AND ECONOMY IN GOVERNMENT

OF THE

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LETTERS OF TRANSMITTAL

OCTOBER 22, 1976.

To the Members of the Joint Economic Committee:

Transmitted herewith is a compendium of papers entitled "Priorities and Efficiency in Federal Research and Development," prepared for the Subcommittee on Priorities and Economy in Government and the Library of Congress by William D. Carey, Louis Fisher, Edwin Mansfield, Albert H. Rubenstein and Lester C. Thurow.

This compendium results from Senator William Proxmire's concern about the allocation of Federal funds for research and development and the way those funds are spent. In view of the large annual outlays in this area, the Subcommittee saw a need to obtain independent reviews by outside experts of the procedures followed by the executive and legislative branches, and assessments of the quality of information available, in the determination of research and development priorities, policies, programs and project support levels.

As the studies concern ways to improve research and development allocation decisions and enhance the beneficial effects of research and development on the economy, I believe the Members of the Joint Economic Committee will find them most useful.

The responsibility for planning, coordinating and editing the studies was carried out by Richard F. Kaufman, General Counsel of the Committee, Susan Doscher Underwood of the Library of Congress, and Larry Yuspeh of the Committee staff. The assistance of Walter Hahn of the Library of Congress and Ellen Crosby of the Committee staff is gratefully acknowledged.

The views expressed in the study are those of the authors and do not necessarily represent the views of the Members of the Joint Economic Committee.

HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee.

OCTOBER 18, 1976.

Hon. HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee,
U.S. Congress, Washington, D.C.

DEAR MR. CHAIRMAN: Transmitted herewith is a compendium entitled "Priorities and Efficiency in Federal Research and Development." The compendium consists of five studies authored by William D. Carey, Louis Fisher, Edwin Mansfield, Albert H. Rubenstein, and Lester C. Thurow.

The Subcommittee on Priorities and Economy in Government has long been concerned with the way Federal funds for research and

development are allocated and spent. An estimated $23.5 billion will be spent by the Federal Government for research and development in fiscal year 1977. Of that sum about $14.9 billion or 63 percent will be spent for military and space activities. The Subcommittee saw a need to obtain independent studies from outside experts because of the high annual outlays of public funds, their concentration in the areas of military and space activities, the fragmentation and apparent lack of coordination of decisionmaking and review in the executive and legislative branches and the absence of good information about the economic and social benefits of research and development.

The compendium was undertaken to shed light on the way Federal research and development decisions are made, the relative priorities of different types of activities, the results of federally supported programs, and their effects on the economy. It was hoped that the studies would highlight the strengths and weaknesses in existing decisionmaking procedures. I believe the studies accomplish the intended purposes and that they also underline the need for additional studies.

The studies were performed under five topic areas selected by the Subcommittee and the Library of Congress. For each topic, a series of issues of particular interest were developed to serve as general guidelines to the authors.

The responsibility for planning, coordinating and editing the studies was carried out by Richard F. Kaufman, General Counsel of the Committee, Susan Doscher Underwood of the Library of Congress, and Larry Yuspeh of the Committee staff. The assistance of Walter Hahn of the Library of Congress and Ellen Crosby of the Committee staff is gratefully acknowledged.

Sincerely,

William Proxmire,
Chairman, Subcommittee on Priorities and Economy in Government.

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THE RELATIONSHIP BETWEEN DEFENSE-RELATED AND CIVILIAN-ORIENTED RESEARCH AND DEVELOPMENT PRIORITIES

By Lester C. Thurow*

I. Historical Allocations

The period from the end of the Korean war to the middle of the Vietnam war was one of growing research and development efforts on all fronts. Dollar spending rose fivefold from 1953 to 1969; real spending rose over threefold. As a fraction of the Gross National Product, R. & D. expenditures doubled from 1½ percent to 3 percent. The shares of different R. & D. sectors rose and fell as the growth rates of different sectors fell behind or lead other sectors, but all sectors experienced rapid real growth.

Defense peaked at 53 percent of the total effort at the height of the missile gap in 1959. Space reached its maximum share at 20 percent of the total in 1965 in the all out effort to place a man on the moon. With rapidly rising defense and space R. & D. private civilian expenditures fell from 47 percent to 35 percent of the total effort in 1963, but by 1974 they had returned to 47 percent of the total effort. Federal civilian R. & D., heavily medical R. & D., rose slowly from 5 to 15 percent of the total effort before leveling off. (See table 1.)

TABLE 1[1]

[Percent of total R. & D.]

Year	Total R. & D. (dollars in billions)	R. & D. as percent of GNP	Private civilian	Total Federal	Federal defense	Federal space	Federal civilian	Federal R. & D as percent of Federal expenditures
1953	5,207	1.4	47.0	53.0	47.8	0.8	4.7	3.6
1954	5,738	1.6	45.3	54.7	48.2	.9	5.6	4.4
1955	6,279	1.6	44.1	55.9	47.4	1.0	7.5	5.1
1956	8,483	2.0	42.7	57.3	48.6	.9	7.8	6.8
1957	9,912	2.2	38.3	61.7	52.2	1.0	8.5	7.7
1958	10,870	2.4	37.5	62.5	52.0	1.0	9.5	7.6
1959	12,540	2.6	35.7	64.3	53.3	2.5	8.5	8.9
1960	13,730	2.7	36.3	63.7	51.6	3.1	9.0	9.4
1961	14,552	2.8	36.3	63.7	49.2	5.5	9.0	9.1
1962	15,665	2.8	36.7	63.3	47.0	6.7	9.6	9.0
1963	17,371	2.9	35.4	64.6	40.6	13.7	10.3	9.8
1964	19,214	3.0	34.7	65.3	36.1	18.7	10.7	10.6
1965	20,439	3.0	36.2	63.8	32.3	20.4	11.1	10.5
1966	22,264	3.0	37.1	62.9	32.0	19.0	11.9	9.8
1967	23,613	3.0	39.0	61.0	33.9	14.3	12.8	8.8
1968	25,119	2.9	40.5	59.5	33.9	13.1	12.5	8.2
1969	26,169	2.8	43.0	57.0	33.5	11.1	12.4	7.9
1970	26,545	2.7	44.4	55.6	32.1	10.2	13.3	7.3
1971	27,336	2.6	45.1	54.9	31.0	9.1	14.8	6.8
1972	29,208	2.5	44.8	55.2	29.5	10.5	15.2	6.6
1973	30,630	2.4	45.8	54.2	28.7	10.2	15.3	6.3
1974	32,100	2.3	46.9	53.1	29.8	9.0	15.2	5.7

[1] National Science Foundation "National Patterns of R. & D. Resources, 1953–1974." Government Printing Office, 1974, p. 30.

*Mr. Thurow is a professor of economics and management, Massachusetts Institute of Technology, Cambridge, Mass.

By 1969, R. & D. expenditures had quit growing.[1] Military and space expenditures were falling faster than civilian expenditures were expanding. By 1972 both private and Federal civilian real expenditures were also falling. Total R. & D. retreated from its peak of 3 percent of GNP to 2.3 percent of GNP in 1974 with the end of a declining share clearly not yet in sight.

II. A False Dichotomy: Civilian Versus Military

This paper focuses on the interrelationships between civilian and military R. & D., but this interrelationship should not be taken to mean civilian versus military R. & D. Any attempt to dichotomize R. & D. into two neat categories, civilian and military, and to then make choices between the two is a mistake. Ultimately choices must be made between civilian and military priorities, but there are many issues that span both sectors. Subsectors with the military or civilian budgets are often more similar to subsectors in the other area than they are to other subsectors in their own budget. Often it is impossible to tell whether research is civilian or military.

Initial researchers in atomic physics did not know that their research would lead to the atomic bomb or to nuclear powerplants. Was this research military or civilian? Medical treatments for gun shot wounds have obvious military applications but in the normal year there are many more civilian gun shot wounds than military gun shot wounds. Is research on treating gun shot wounds military or civilian? Research on treating casualties from nuclear fallout during wars is obviously military research yet it is pertinent to accidents in nuclear power plants and has more in common with health and environmental research than it does with research on weapons systems for destroying lives and property. Research on chemicals to retard or stimulate plant growth may be equally useful in both the civilian and military areas.

As these examples indicate the allocation of research and development funds requires a more complex form of analysis that any simple categorization into military and civilian will allow. In the end, however, it is only by building up this more complex mode of analysis that will make it possible to make intelligent choices between military and civilian R. & D. expenditures.

III. A Limited Role for Cost-Benefit Analysis

In theory R. & D. expenditures could be determined in an application of cost-benefit analysis. Using an appropriate interest rate to reflect the value of alternative uses of funds, discounted benefits could be compared with discounted costs. Wherever discounted benefits exceed discounted costs projects would be undertaken. Wherever dis-

[1] Unless it is possible to measure output it is not possible to construct an accurate deflator to determine real expenditures. Since R. & D. output cannot be accurately measured, current dollar expenditures are deflated by a deflator that is made up of 50 percent of the GNP deflator for services, 25 percent of the GNP deflator for durable goods, and 25 percent of the GNP deflator for structures.

counted costs exceed discounted benefits, projects would be rejected.[2] Optimum total expenditures are simply the summation of all of the economically viable R. & D. projects and each sector's share is similarly determined by how many of its projects can generate positive net present values.[3]

In practice the formalized structure of cost-benefit analysis is of little help in determining total R. & D. budgets or in its allocation to sectors. In R. & D. the fundamental fact of life is uncertainty. The policy planner and the researcher are always uncertain as to how many benefits will emerge and are often uncertain even about the types of benefits that will emerge.

It is important to understand that uncertainty is fundamentally different than risk. With risk a project may succeed or fail, but the policy planner has some idea of the objective probabilities of success or failure. As a result he can apply simple mathematical tools to use expected values (or whatever other measure his loss function would imply) in his cost-benefit analysis. The anlysis becomes slightly more complex with risk, but is basically unchanged.

In the case of uncertainty the planner does not know the objective probabilities of success or failure and cannot use mathematics to convert his problem into one suitable for formal cost-benefit analysis. Unfortunately, the R. & D. process is not so much risky as it is uncertain. This means that it is impossible to estimate objective costs and benefits. Instead it is necessary to use subjective estimates of knowledgeable individuals as to what costs and benefits might be. There are no analytical estimates. This means the real problem is to pick the best or most accurate subjective estimate or the *range* of possible costs and benefits.

Constructing subjective estimates of costs and benefits and picking the most likely subjective estimates can be described as cost-benefit analysis, but it is not; it is fundamentally different. It involves an uncertainty and a degree of choice that turns the problem into one far different from that designed to be solved by the formalized application of cost-benefit analysis.

R. & D. also suffers from the problem of non commensurability that afflicts many other expenditure areas. Benefits or objectives are not easily or naturally comparable. What is the relative weight to be assigned cancer prevention versus national defense? Do lives saved in each activity count equally? When economists talk about non-commensurability they simply mean that it is impossible to compare two sets of benefits without making explicit *value judgments* about the relative

---

[2]

$$NPV=\sum_{t=1}^{n}\frac{B_t}{(1+i)^t}-\sum_{t=1}^{n}\frac{C_t}{(1+i)^t}$$

NPV = net present value
B = benefits
C = costs
i = discount rate
t = time

[3] For a discussion of the analytical techniques of cost benefit analysis see: Stephen Marglin, *Public Investment Criteria: Benefit-Cost Analysis for Planned Economic Growth.* MIT Press, Cambridge, 1967.

worth of two objectives. Fortunately or unfortunately there are no analytical techniques that will let the policy maker (Congress or the President) avoid the difficult moral problem of having to assign weights to the relative worth of national defense and curing cancer. These social moral judgments simply must come out of the political process.

Because of the value judgment problem cost-benefit analysis has seldom been used to compare programs in different areas of government. Instead cost-effectiveness analysis is used within separate areas to determine the best techniques for obtaining some objective without any effort to determine the relative worth of different objectives in different areas. Since R. & D. expenditures cover many different areas, the value judgment problem cannot be ignored.

This does not mean that policy makers will not eventually have to determine the relative weights of cancer and national defense. In setting their budgets they implicitly do and will make such decisions, but there is no analytically correct way to make such decisions. The problem is simply one of judgment and the judgment nature of the problem cannot be changed by semantically describing the judgment as cost-benefit analysis. To do so is only to obscure the true nature of the problem.[4]

Because of the preceding problems, cost-benefit analysis has seldom been used in allocating R. & D. Various pieces of the apparatus, however. could be modified and used to improve the allocation of R. &. D. funds. If there were one procedure that might improve the process of R. & D. budgeting, it would be to insist that all projects show a *range* of possible costs and benefits. Ideally each project should show *ranges* of possible costs and benefits estimated by *more than one* individual or group. It cannot be emphasized too much that any single dollar estimate (point estimate) is fundamentally misleading. With uncertainty no one knows the cost and benefits of any R. & D. projects. At best they can only know the range of possible costs and benefits. Given this reality, neither the Congress nor the President should make their decisions using point estimates in their deliberations on either military or civilian projects.

In addition to ranges of probable costs and benefits, each project should have an estimate of the maximum possible benefit that could be expected, it would, for example, be relatively easy to calculate the economic benefits of an R. & D. breakthrough that let us double the yield of soybeans. The probable costs and benefits might not be known with any accuracy, but the maximum benefits might be known with great accuracy.

Having an estimate of maximum gains makes it possible to compare the range of estimated costs with the maximum gains to see if the project makes any economic sense. An excess of the maximum benefits over the range of possible costs does not guarantee that the project will yield positive net benefits (costs may exceed the expected range or the maximum benefits might not occur) but it probably constitutes a good minimum criterion. If the maximum possible gains do not exceed the range of possible costs by some substantial margin, the project should not be undertaken. At the very least maximum benefit calcula-

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[4] For a discussion of the limitations of cost benefit analysis see: Peter O. Steiner. "Public Expenditure Budgeting", in *The Economics of Public Finance*. The Brookings Institution, 1974.

tions place an upper bound on the size of programs that should be mounted in different areas. They also force the proponent of any program to state what the benefits are supposed to be.

While it may not be desirable to place an explicit dollar value on all objectives, similar maximum benefit calculations should be made in each area. Everything else being equal a disease killing only a few people does not merit the effort of a disease killing many people. The maximum benefits of programs saving lives should be compared with each other even if they are not analytically compared with programs that generate monetary gains.[5] The same holds true for military programs.

Leaving aside basic research for the moment, applied research and development expenditures should be reviewed by lumping together those expenditures that generate commensurate benefits. Within each area analytical studies could be undertaken as to the relative merits of different projects even if informed judgment is ultimately necessary to make selections across areas with non-commensurate benefits.

A variety of divisions could be suggested, but I would suggest a four category split—national independence, life saving, economic goods and services, and non-economic quality of life goods and services. The national independence category would include research on defense, space, foreign affairs, and intelligence. The life saving category would include research on health, safety, wartime casualties and environment programs designed to save lives. The economic goods and services category would include research designed to development or improve economic goods and services. The non-economic quality of life goods and services category would include research and development on those goods and services that contribute to the quality of life but which are not conventionally sold in the U.S. economy (clean air, etc.).

The reasons for this fourway breakdown are twofold. First, comparisons should be made across as wide an area as is feasible. Non-commensurability certainly exists, but it should not be exaggerated. For example, it is possible to compare the effectiveness of various projects for preserving national independence even if it is not possible to compare these programs with life saving programs, economic programs, or non-economic (quality of life?) programs. Similarly each of the other areas with the possible exception of non-economic goods and services has a natural unit of measurement. We can evaluate life saving programs in terms of the number of lives saved and economic programs can be evaluated in terms of the extra dollars of GNP generated or re-allocated. Non-economic quality of life goods and services are more diverse and thus harder to compare with each other, but even here a few general measures (indexes of pollution, social unrest, etc.) might be used to compare different R. & D. programs.

Within each of the four areas, individual R. & D. projects would be expected to give a range, and even more desirably several ranges, of possible costs and benefits and an estimate of maximum benefits. Benefits will be specified differently in the different areas—capacity to destroy lives, capacity to save lives, dollar gains, etc.—but benefits would

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[5] In fact dollar estimates are placed on human life using what is called the value of statistical human life. This value is gotten by observing the monetary premiums that individuals must be paid to accept jobs with a higher probability of being killed on the job or the premiums that they are willing to pay to lower their probability of being killed in traffic accidents or other areas where death is possible.

be nonetheless specified. Institutionally this would require that both the executive and congressional branches of government organize themselves to look at commensurate programs rather than leaving the programs spread out in the agencies that are to administer them and the committees which supervise these agencies.

IV. Supporting Basic Capabilities

In addition to the distinction between military and civilian research, the other traditional distinction has been between that of basic research, applied research, and development. In 1974, 14 percent of the $32 billion in total R. & D. spending went into basic research 23 percent went into applied research, and 63 percent went into development. As the data in table 2 indicate basic research is 60-percent financed by government with universities contributing another 20 percent of the financing. Universities spending 64 percent of the total funds, however. Within the $2.6 billion of Federal funds for basic research, NASA provides $0.7 billion, HEW provides $0.6 billion, the NSF provides $0.4 billion, the AEC provides $0.3 billion, and the DOD provides $0.3 billion with the remaining $0.3 billion being spread across the rest of government.

At the applied research level government funding drops to 52 percent of the total with industry funding rising to 40 percent of the total. Private industries perform 54 percent of all applied research with government performing slightly more of what remains than universities (22 percent versus 17 percent). Private industries are a substantial net recipient of funds at the applied research level. In the development area the federal government funds 52 percent of the total bill with all of the rest of the financing coming from private industries which do 83 percent of the total work. Most of the remaining work is done by government with a very small role for both universities and other nonprofit institutions.

TABLE 2.[1]—PERFORMANCE AND FUNDING OF R. & D., 1974

Institutions	Total R. & D. performance (percent)	Source of funds	Basic research performance (percent)	Source of funds	Applied research performance (percent)	Source of funds	Development performance	Source of funds
Government	15	53	13	60	22	52	13	52
Industry	67	41	17	15	54	40	83	47
Universities	15	4	64	20	17	6	2	0
Other nonprofit	4	1	6	5	7	2	2	0

[1] NSF, op. cit., p 4–5.

While the distinctions between basic research, applied research, and development are useful from some perspectives, they are not particularly useful from the point of view of expenditure allocation. A more useful tripart categorization would be "basic capabilities R. & D.", "mission oriented R. & D.", and the occasional highly focused allout efforts represented by the Manhattan project, the man-on-the-moon program and perhaps the war on cancer. For lack of a better name the latter might be called "massive mobilization R. & D.". All three of

these categories would contain basic research, applied research, and development.

"Basic capabilities R. & D." is designed to build up a general fund of knowledge from which mission oriented R. & D. and massive mobilization. R. & D. can flow and to maintain a level of capabilities that will allow the country to rapidly take advantage of scientific break-throughs wherever they may occur and whoever may make them. Mission orientated R. & D. is more focused in the sense that it is possible to state where benefits are to be expected and the breakthroughs that would be necessary to achieve the desired benefits. Massive mobilization R. & D. would occur when the mission was highly defined, when the basic scientific knowledge existed to support a massive effort, and when the benefits were perceived as so large that the country was willing to devote a significant fraction of its resources to achieving these specific objectives.

While basic capabilities research would include some of what is now called basic research, most basic research is mission orientated. Conversely, a limited portion of applied research and probably an even more limited portion of development expenditures should be considered basic capabilities research. Basic capabilities can be labelled neither military nor civilian since they are necessary for both areas and may lead to break-throughs in either. They form, establish, and maintain that fund of knowledge and human skills out of which it is possible to make either civilian or military progress.

Historically basic capabilities R. & D. has been funded out of whatever mission orientated R. & D. budget is popular enough to stand the strain. At one point the DOD R. & D. budget financed much of our support of basic capabilities. Later the burden was shifted toward space and in more recent years toward HEW and the "war on cancer." In theory the National Science Foundation exists for this purpose, but it has never obtained the political popularity and size to undertake the support of basic capabilities in addition to its mission orientated projects. Instead we pretend that "basic capabilities" research is in fact functional mission orientated research in the latest area of popular interest.

If rational R. & D. allocation procedures are to be followed it is necessary to think directly about the level of funding necessary to support basic capabilities. As long as it is buried in other budgets it cannot rationally be analyzed or supported. There is no reason why this type of research should be called defense, but there is equally no reason why it should be called civilian or part of the "war on cancer." To be funded rationally, it should be called what it is and financed on its own merits. The American government and public has to be sophisticated enough to realize that a certain amount of research has to be done not because it is directly related to current problems, but because it is the way any society diversifies its risks and allows itself to take advantage of the break-throughs that might occur in any area.

While mission oriented research should be funded in proportion to the range of benefits that can be generated in an area and the range of possible costs, basic capabilities should be funded in a very different way. There are two separate ingredients that should go into the funding of basic capabilities.

First, scientific personnel need to be allocated across different research areas so that the country will be aware of break-throughs whereever they occur and so that the country will be able to absorb and take advantage of these break-throughs whenever they do occur. Fundamentally, uncertainty as to where advances will occur means that basic capabilities research expenditures need to be allocated across all possible areas since no one knows or can know where useful advances will occur.

This does not mean that the United States has to be in a position to generate or even lead every break-through in knowledge. It simply has to have enough trained manpower in an area to take advantage of a breakthrough when it occurs. This is true even in areas where other countries are apt to keep advances in knowledge secret. The problem is similar to that encountered in chess books on end-games. Once it is known that a solution is possible—the game can be won in four moves—it is not difficult to find a solution. When the Russians knew that an A-bomb or H-bomb could be made, they did not take long to catch up. Similarly our catch up time in the space area was very short. The difficult problem is to fund a solution to a problem or to advance knowledge when no one knows whether a solution or an advance in knowledge is possible.

Second, to determine the resources necessary to maintain basic capabilities, it is necessary to know how fast knowledge can be disseminated and how fast human skills can be built up in different areas. The faster the knowledge can be disseminated and the faster human skills can be built up, the fewer the resources that need to be permanently maintained in any area.

To determine the amount and allocation of funds necessary to maintain basic capabiilties, it is necessary to survey the different areas of human research to determine the level of funding that would be necessary in each area. It should be emphasized that basic capabilities does not mean current capabilities. Basic capabilities has to do with minimum level of resources necessary to be aware of and absorb the advances in knowledge in any given area and the minimum level of resources consistent with a future need to expand actiivties.

If the distinction is made between hot field where useful knowledge is expanding rapidly and cold fields where knowledge is not expanding rapily or cannot easily be used, basic capabilities has to do with the amount of resources that is necessary to keep a cold field in business. It is to be expected that hot field will be allocated funds for basic research, applied research, and development over and above what would be allocated to cold fields.

In trying to determine the desirable level of funding for basic capabilities, it is necessary to go beyond the traditional disciplinary areas (physics, chemistry, etc.) that have developed in the science and engineering areas to a more functional approach that will cut across traditional disciplinary lines. A variety of categorizations are possible but I would suggest the following one:

1. Life Sciences.
2. Agricultural Sciences.
3. Environmental Sciences.
4. Material Sciences.
5. Energy Sciences.

6. Behavioral Sciences.
7. Logical Sciences (math, statistics, computer science etc.).
8. Space Sciences.
9. Equipment Sciences.

Such a categorization can be useful from two perspectives. First it is output orientated and focuses attention on the functional areas in which we are ultimately interested. Second, since it cuts across traditional disciplinary lines, it is easier to start from ground zero to determine the resources that are needed in each area. Vested interests are much less clearly defined and known. We do not know how current funds are split along these lines. We do not know how funding along these lines would affect different disciplines. Different individuals within the same discipline would have different interests. As a result such a categorization is much more likely to generate realistic estimates of the funds necessary to support basic capabilities than any categorization that closely follows current breakdowns. Using the current categories is apt to produce a defense of the status quo.

While basic capabilities research would be funded in accordance with the effort needed to maintain basic capabilities in each of the nine suggested areas, mission orientated research would be funded in accordance with the modified cost-benefit principles outlined earlier. Each project would have several estimates of ranges of possible benefits and costs and an estimate of the maximum possible benefits. Using this data, projects would be funded relative to some combination of the probable net benefits but would never be funded in such a manner as to exceed the maximum possible benefits.

Massive mobilization R. & D. would not be subject to such cost benefit analysis. By the very fact that the research has the character of a massive mobilization, society is certifying that the benefits approach infinity and that therefore it is willing to spend whatever is necessary over time and whatever can be efficiently spent at any moment in time. Ex-post massive mobilization R. & D. may be a failure or a success, but ex-anti it will always appear as a project that must be done. If it doesn't, it will fall into the category of mission orientated R. & D.

As a result if you think of funding patterns, basic capabilities R. & D. would be funded in a rather egalitarian manner, mission orientated R. & D. would be funded in accordance with modified cost-benefit analysis, and massive mobilization research would be funded in a completely inegalitarian manner. Only occasionally would such projects even exist, but when they did, they would consume a large fraction of the total national A. & D. budget.

V. Some Often Considered But Properly Neglected Benefits

In discussing military and space research reference is ofen made to the civilian benefits from military and space spinoffs. The magnitude and importance of civilian spinoffs is a subject of dispute, but it is important to realize that spinoffs do not justify specific types of research regardless of whether they do or do not exist.

First, there is great uncertainty as to whether spinoffs will occur in any research. Being uncertain and to a great extent random they cannot be used as a justification for any particular project. Second, spinoffs can occur in any kind of research. Useful military knowledge

is just as likely to be spunoff from civilian research projects as useful civilian knowledge is to be spunoff from military research. As a consequence, spinoffs cannot be used as an argument to increase the share going to either military or civilian projects. Third, spinoffs are apt to be an inefficient way to achieve any goal. If some goal is desired, research should be directly focused on this goal rather than hoping that the solution will come from some project focused on a different goal. The problem is exactly equivalent to the old saw about studying Latin to improve your English. Etudying Latin may improve your English but the same number of hours devoted to the study of English would do much more for your English.

Since spinoffs can occur in any kind of research they are something to consider in deciding what fraction of the national resources should be devoted to R. & D. but they are not something that can be used to decide how R. & D. expenditures should be allocated to different sectors.

Just as the benefits of spinoffs should be ignored in allocating research funds so should the benefits of economic multipliers. All exogenous increases in expenditures are multiplied in the economy since expenditures create incomes that lead to rising expenditures by those who benefited from the initial rise in expenditures. This second round of expenditures leads to a second round of income increase and hence to further rounds of rising expenditures and incomes. While the effects of any expenditure are multiplied through this process, multipliers and multiplied benefits should not be considered in determining either the total R. & D. budget or its allocation.

Since all expenditure projects (research and development or otherwise) have approximately the same multiplier effect per dollar of expenditures, multipliers do not help differentiate among projects—military or civilian. But in contrast to spin-offs they also do not help you determine the correct aggregate amount to be allocated to research or to any other expenditure project. They don't for a very simple reason. If all that you want are macro-economic multiplier effects there is a project that dominates all other projects because it generates multiplier effects without having to sacrifice real resources. This project is called a tax cut. As a result all expenditure projects must be evaluated on the basis of their direct rather than their indirect benefits. If they cannot be justified in terms of direct benefits they cannot be justified.

As a result, both civilian and military R. & D. expenditures should be judged on the direct benefits that they are suppposed to be producing. In terms of secondary economic benefits, the differences are the second order of smalls and should be ignored in decision making.

VI. Justifying Inputs in Terms of Outputs

Logically historical data and good feedback principles should be a reasonable place to search for guiding principles to determine R. & D. expenditures and their allocation. Expand research where it has demonstrated success: contract research where it has not demonstrated success; allocate funds to those sectors where ouputs have been rising as the result of new knowledge gained from R. & D.

The basic problem is that it is impossible to make an output-based argument for R. & D. expenditures in either the military or civilian area. In both areas it is possible to point to new and better products that have been developed—better submarines, better calculators, diseases cured—but in both areas systematic efforts to look for improvements in outputs, as opposed to improvements in inputs, fail to come up with much.

Consider the civilian economy. As we have seen there has been a large increase in the absolute and relative effort going into all forms of R. & D. in the post-World War II period. Yet measures of the rate of growth of our real standard of living (GNP per capita, output per manhour, etc.) indicate no corresponding acceleration. Our real standard of living is not rising faster than when we were making a smaller R. & D. effort. (See table 3).

The same problem is visible in the life saving area. Diseases have been cured (polio), wondrous new machines exist yet the average life expectancy has been stagnant or growing more slowly than in countries without large medical R. & D. expenditures. We spend more on medical research and development than any other country in the world yet now rank 24th in terms of average male life expectancy and are continually falling relative to the rest of the world.[6] (See table 4.)

TABLE 3[1]

[1950=100]

Year	Per capita GNP (1958 dollars)	Output per man-hour (private economy)	R. & D. expenditure (1958 dollars)
1950	100	100	100
1955	113	117	117
1960	116	131	225
1965	136	158	313
1970	151	174	333
1971	155	181	328
1972	163	187	339
1973	171	192	337
1974	166	187	320

[1] "Economic Report of the President" 1975, p. 250, 287, 275.

TABLE 4[1].—EXPECTATION OF LIFE

Year	At birth (years)	At age 65	
		Males	Female
1920	54		
1930	60		
1940	63	12	14
1950	68	13	15
1960	70	13	16
1970	71	13	17
1972	71	13	17

[1] "Statistical Abstract of the United States", 1974, p. 58.

The same problem is also visible if you look at the output measures of military research. Vast amounts of R. & D. and improved technical inputs have not allowed the United States to win wars in either Korea or Vietnam—even though we were fighting what everyone agrees was

[6] United Nations Statistical Yearbook, 1974, p. 80.

a technologically inferior enemy. Based on actual outputs military R. & D. has been a failure.

The previous paragraph is clearly unfair to military research, but so are the prior paragraphs to civilian R. & D. designed to raise standards of living or increase life expectancy. In each area each of us could name other factors that explain the lack of "output". But these other factors are real. If they exist and stop research from having its payoff then this is a fact that must be taken into account when determining R. & D. budgets. It does no good to design a train that will run at 200 m.p.h. if no track can withstand trains going more than 40 m.p.h. If you are not going to do something about the tracks there is no sense wasting R. & D. resources on trains.

In each of the economic, life saving, and military cases it is possible to give explanations as to why R. & D. has not lead to the desired outputs or why the outputs may be higher than they seem to be. For example, in the economic area there is a bias in the way that real dollar output is measured. United States R. & D. is heavily orientated toward new products rather than new and cheaper methods of producing old products. But the prices of new products do not showup in the indexes used to deflate nominal output until the product has achieved a degree of use and market penetration that makes them a significant fraction of the GNP or the average family's purchased basket of goods or services. Neither of these is apt to occur until a product is well down its learning curve and sold at prices far below its initial introductory price. At this point the good is weighted into the constant dollar output estimates. But since the current dollar price has declined substantially, the new good will receive a much lower weight than it would have if it had been inserted at its initial selling price. Thus hand calculators may be valued as $100 worth of constant dollar output rather than at the $1.000 price for which they first sold.

In the health area increases in environment pollution or deteriorations in diet and exercise might well be reducing life expectancy if it were not for the progress made in curing individual diseases. In the military area the new technologies have not been tested in a no-holds-barred war to see if they would be effective and they might have been effective at deterring wars even if they have not been effective at winning wars.

Institutional constraints may also prevent advances in knowledge from being used. As I mentioned previously, it makes no sense to develop a 200 m.p.h. train as long as the road-beds will only permit maximum speeds of 40 m.p.h. Union work rules may prevent new technologies (such as those in printing) from being adopted as fast as they should be. The Air Force's attachment to manned bombers may prevent the Defense Department from substituting more effective submarines for bombers as fast as they ought. A few years ago, it would have been conventional wisdom to say that the institutional and human constraints on the adoption of new products and processes was greater in the civilian area than the military area, but the history of the past decade makes this a very dubious proposition. It would now be hard to argue that there were more constraints in one sector than the other. As always, the problem is to know what constraints must be accepted and what constraints must be broken.

Such constraints must, however, be taken into account in R. & D. allocations. If constraints are not in fact going to be changed, allocating R. & D. expenditures to these areas is a pure waste of resources. Thus on mission orientated research there should be some explicit consideration of the constraint problem in the R. & D. allocation process.

Comparing R. & D. inputs and final outputs leads to a fundamental conundrum. Many indicators indicate that we have been very successful at the microlevel. Wondrous things have been discovered and invented. Yet macro indicators of success almost universally fail to record the impacts of these microsuccesses. One can always argue that things would have been worse without these mircosuccesses, but this is hardly the most convincing argument.

The lack of "output results" should not be taken as an argument for doing away with R. & D. To quit learning new things is hardly a policy that commends itself in either the military or civilian area. The lack of macrosuccess does however mean that we need to think seriously of ways in which R. & D. can be better funnelled into either the civilian or military sectors of society. For be it quicksand or rock, the output foundation of military and civilian research are equally firm or flimsy.

The standard response to this problem has been to advocate more applied research and development and less basic research. This is to fundamentally mis-diagnose the nature of the problem. The problem is not a surplus of basic knowledge that goes unused for lack of development, but developments that cannot be put in practice because of various institutional obstacles. The solution lies not in re-allocating research expenditures from basic to applied, but in reforming the process whereby applied knowledge is brought into actual use.

VI. Different Adoption Structures

Research leads to new products, better products, or to better ways of producing old products. If research leads to new products, it raises the output per unit of input. If it leads to better techniques, it lowers inputs necessary to produce old products. In either case, research leads to higher productivity.

Perhaps the relationship can be best understood in the context of the following mode (see fig. 1). Assume that knowledge is arranged in a continuum from the most productive technique to the least productive technique. (Similar continuums could be constructed for product innovation or improvement.) On the far right there is a frontier of scientific knowledge. Well behind this there is a frontier of engineering knowledge, and well behind this, there is a frontier given by the best actually operating technique. But all plants do not use or even know about the best operating techniques. To the extent that the best techniques must be embodied in physical capital, they cannot use the best techniques without scraping all of the old plant and equipment and buying new.

Typically, the spectrum between the highest productivity plant in operation and the lowest productivity plant in operations covers a range of productivities on the order of four to one, with a distribution of plants in between. To the left of the worst operating plant is a range of techniques that have become obsolete. The distribution curve

is moving to the right (as are the various frontiers) with respect to any particular product.

Productivity, however, only depends upon the range between the best and worst practice plants, the distribution of plants within this range, the location of the range on the continuum, and the speed with which the whole distribution is moving to the right. The frontiers of engineering and science are relevant only in that they are a kind of road-building operation, whose speed limits the possible speed of movement toward higher productivity techniques.[7]

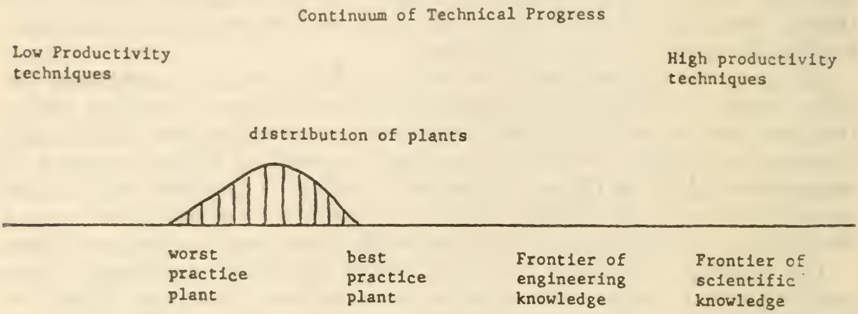

FIGURE 1

While figure 1 is applicable to either military or civilian research there are differences. The gap between the scientific frontier and the engineering frontier partly depends on how much R. & D. effort is made. While there is now more civilian than military or space R. & D., the civilian R. & D. covers a much wider range of products. In the military sector there is more R. & D. per product line. This is apt to push the frontier of engineering knowledge closer to the frontier of scientific knowledge and may even push the frontier of scientific knowledge out at a faster rate. But the big differences are not apt to lay in either the speed of movement or the gap between the frontier of engineering knowledge and the frontier of scientific knowledge.

The big difference is apt to lay in the gap between the frontier of engineering knowledge and the best techniques or products that are actually used. In the military area products are rushed into production when it becomes technically possible to build a product. This is what gives one nation a technical military edge over another nation. In the civilian area, products must meet a constraint other than that set by "buildability".

In the civilian sector new processes are not adopted for new plants unless the cost of the new process is lower than that of the old process and new processes do not replace existing plants unless the total cost of the new process is less than the marginal cost of the old process. New products are not put into production unless the product is so superior that individuals will be willing to give up old products and reallocate their income to the purchase of a new product. Thus there is a set of economic constraints that any process or product must meet in addition to the engineering constraints of doability. Economic

[7] For a more extensive discussion of these issues see: "Research, Technical Progress, and Economic Growth", *Technology Review,* March 1971, p. 44.

budget constraints also exist in the military area (more at sometimes than others) but they are much less binding. This leads to a much larger gap between engineering feasibility and best practice in the civilian area. Probably the best example of the difference is found in nuclear powered ships. They have now been used in the Navy for decades but have yet to be put into regular commercial use.

The civilian medical research area, however, tends to have some of the same characteristics of military research. The desire for extended life is strong enough that new products and processes tend to be put into use as soon as they have met tests of engineering feasibility and almost regardless of cost. In both the military and medical areas we perceive an all or nothing choice. Nothing replaces defense and nothing replaces life. As a result, narrow economic calculations do not impose themselves to the same degree. While tests of economic feasibility are certainly appropriate in the area of economic goods and services, they leave out an important externality that is apt to exist in the adoption process.

The imposition of economic constraints is apt to have an effect beyond that of a longer lag between best practice and the engineering frontier and a wider distribution between the best and worst plants in operation. Most new products and processes are subject to a learning curve. As the products are actually put into production there are a host of small scale technical breakthroughs. In addition the labor force gains proficiency in the skills that will actually be used in production. The net effect is rapidly falling unit costs as production proceeds. Hand electronic calculators are probably the best current civilian example of falling costs. Thus an important part of the R. & D. process occurs after production decisions have been made and laboratory feasibility has already been established.[8]

The initial period of high unit costs presents an economic problem. How are they to be covered? In the defense area, government is the buyer and contracts are signed for production runs that take into account what we know about the learning curve phenomenon. One of the reasons for the high cost of the space program is that it does not get the advantage of any lengthy production runs and falling unit costs. The space program simply pays high initial costs. In the medical area, government and individuals are willing to pay very high initial costs if lives are saved. In the civilian non-medical area none of these situations exist. Costs fall as production occurs, but initial costs must fall to a much lower level before production can begin. In the non-medical civilian area substitutes almost always exist, even if inferior, and these set a ceiling on the maximum costs than can be recovered. Modular housing provides a good example of being unable to get production runs long enough to proceed far enough down the learning curve to be competitive with conventional housing. This is due to both the high initial cost and to the fact that everyone is uncertain as to whether the learning curve will level-off at a lower or higher level than the cost of conventional housing.

What this means is that non-medical civilian research efforts must be more careful in considering the learning curve phenomenon if the

[8] A. D. Searle, "Productivity Changes in Selected Wartime Ship Building Programs," *Monthly Labor Review*, vol. 61, No. 6, December 1945.

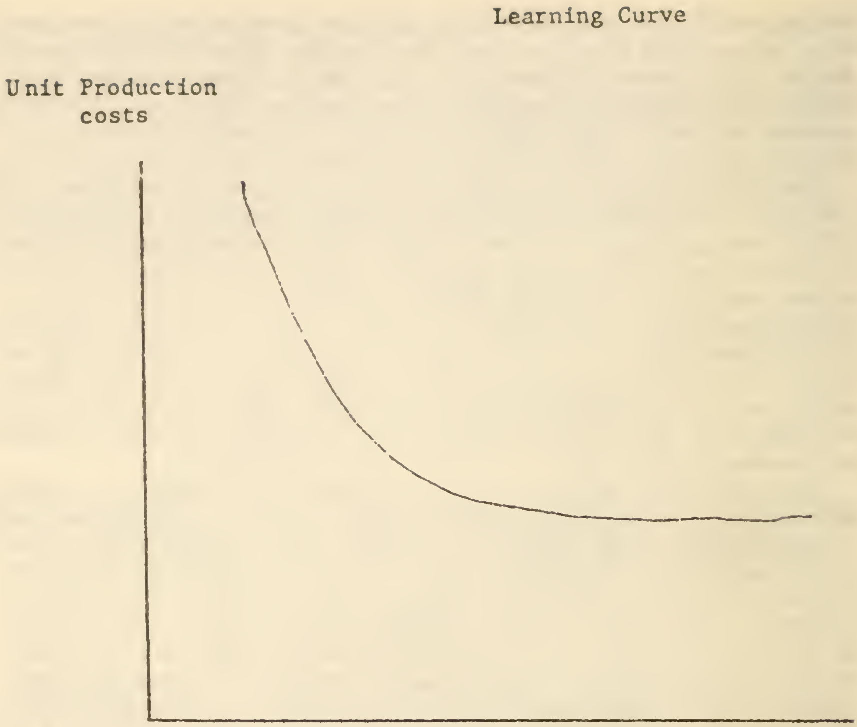

DIAGRAM 1

full range of R. & D. benefits is to be generated. Some substantial fraction of R. & D. must occur in the process of beginning production. If production is never begun, the necessary R. & D. will never be done and the initial R. & D. expenditures will have been wasted.

As we have seen development expenditures and especially civilian development expenditures are almost entirely financed by private industry. While this is appropriate when there are no externalities, the learning curve is essentially an externality. If one firm goes down its learning curves other firms can quickly guess what the learning curve looks like by the pricing and production policies of their competitor. The first firm must bear the uncertain cost of failure (i.e. the learning was not steep enough to generate profitable sales) while all firms gain the knowledge the trip was either profitable or unprofitable. These uncertain costs can serve as a barrier to enter for each individual firm even though they could not be a barrier to entry if spread across the entire industry.

The externalities involved in the learning curve mean that the government probably withdraws from the civilian research area too early to gain the full economic benefits that are possible. Serious consideration should be given to subsidized initial production runs on the understanding that all cost data would be made public as it was being generated. In other sectors—space, medical, defense—government already does this by being the principle buyer. Commensurate gains

will require the same kind of action in the non-medical civilian area. Unless some effort is made to achieve the learning curve benefits that automatically occur in the defense and medical area, civilian economic research is apt to have a lower pay-off and to yield benefits with a much greater time lag.

There is also probably a bias within the U.S. research establishment—military or civilian—toward too much R. & D. on the development of glamorous new products and not enough R. & D. on the less glamorous job of reducing the costs of producing old products. This occurs partly because of the personal interests of scientists and engineers in both the granting and recipient agencies or firms, but partly because of the difficulty of funding cost reduction research in a mixed private public economy. When government funds are used to finance the development of new products, there is always some uncertainty as to exactly who will economically benefit from the new products. Being uncertain as to who will or won't benefit we are willing to go ahead. The economic winners are not known (they may in fact be ourselves) and the economic losers are not clearly identified (even to themselves). With cost-reduction research, however, there is a very clear set of known winners and losers. We know who makes and who buys the product. We know whom a cheaper product will run out of business. The net result is a reluctance on the part of government to get involved in cost-reduction research yet this is exactly the type of research that seems to have yielded the very high rate of growth of productivity in the Japanese economy. Given that most products in the economy will be old products at any point in time, the potential productivity gains from reducing the production costs of old products is much larger than any possible gains from developing new products.

Private firms clearly have an interest in this kind of research, but they face the externality problem mentioned earlier. If they are successful, others will quickly learn that they are successful and as in any end-game problem they will quickly be able to duplicate the results at much less cost or uncertainty than the initial developer.

IX. Misleading Historical Successes

Often R. & D. funds are mis-allocated because hard facts are overwhelmed by the success of the Manhattan Project and the Space Program. In each case it seemed possible to achieve a specific objective—an atomic bomb or a man on the moon—if we were only willing to spend enough money and effort. This leads to the erroneous conclusion that all problems are potentially solvable in a short period of time if we think they are important enough to generate an all-out In fact, this is not the case.

Problems lie in the potentially solvable area only when they fall between the frontier of scientific knowledge and the frontier of engineering knowledge. If the basic scientific facts necessary for a solution are not known, there is no guarantee that a major effort will speed up the solution and there may even be no sensible way of organizing a major effort. To some extent, President Nixon's War on Cancer falls into this domain. Quite sensibly this war did not achieve the scale of either the space program or the Manhattan project, but it probably has achieved a scale that is inefficiently large. It has become a source

of funding for basic capabilities rather than a source of mission funding for directly working on a cure for cancer. While no one quarrels with the need to cure cancer, the fact remains that there is an appropriate time to declare War on Cancer and an inappropriate time. If the war cannot be won it should not be declared.

The decision as to whether there is enough information on hand to achieve some major breakthrough in a relatively short period of time (10 years at the outside) is one hat only those in the field can ascertain. But collection of unbiased opinions is as always difficult. Those who are in the field and can best tell whether a "war" is capable of being won are the same people who most benefit from having a "war" declared. This is not to disparage the honesty of any group of individuals, but it is a natural human phenomenon to be overly optimistic and exaggerate one's capabilities. This is especially true when declaring war is politically popular.

X. Conclusions

There are a variety of actions that could be taken to strengthen the system of research and development in the United States.

(1) Research and development expenditures should be broken into three broad categories—basic capabilities, mission orientated, and massive mobilization.

(2) Funds for basic capabilities should be spent based on analysis of how much it costs to keep enough R. & D. personnel in an area to be aware of any breakthroughs that might occur and to be able to expand rapidly should each breakthrough actually occur. Instead of allocating funds to traditional disciplines, funds should be allocated across life sciences, agricultural sciences, environmental sciences, material sciences, energy sciences, behavior sciences, logical sciences, space sciences, and equipment sciences.

(3) Funds for mission oriented research should be spent based on the modified cost-benefit analysis outlined above. Every project should have ranges of possible benefits and costs along with an estimate of the maximum possible benefit. Wherever possible there should be ranges of costs and benefits estimated by more than one individual or group. Since it is not possible to make analytical comparisons across non-commensurate objectives, mission oriented research should be broken into four types—national independence, life saving, economic goods and services, and non-economic quality of life goods and services.

(4) Massive mobilization research will be funded in accordance with whatever is necessary to achieve the goal over time and in accordance with efficient expenditure rates at any point in time. But massive mobilization research will seldom occur and it will never occur if the basic scientific knowledge does not exist to be relatively confident of success within a 5 to 10 year time period.

(5) Spinoffs and economic multipliers should always be ignored in allocating R. & D. expenditures.

(6) Institutional constraints need to be taken into account in allocating R. & D. expenditures. Unless you are going to improve railroad roadbeds there is no sense in spending money on developing fast trains.

(7) Some proceedure must be developed to overcome the learning curve externality in the non-military non-medical part of the R. & D. budget. The best technique would probably be to continue public R. & D. expenditures farther along the development path but to them insist that all production data and processes be made publically available.

(8) Cost-reduction R. & D. is probably being slighted in favor of new product R. & D. Here again the problem can probably only be solved by changing the current de facto proprietary rights of those who might be hired to do the cost-reduction research. Whatever information is generated must become much more publicly and quickly known if this research is to overcome the political obstacles that it currently faces.

SENATE PROCEDURES FOR AUTHORIZING MILITARY RESEARCH AND DEVELOPMENT

By Louis Fisher*

CONTENTS

The Federal Government will spend an estimated $22.6 billion for research and development during fiscal 1977. Approximately half that amount, $10.7 billion, is scheduled for Defense-Military Functions. The next closest agency, in terms of R&D outlays, is the National Aeronautics and Space Administration ($3.5 billion), followed closely by the Energy Research and Development Administration ($3.0 billion).[1]

The Department of Defense budget request for fiscal 1976 surpassed $100 billion for the first time. Fiscal 1976 also marked the first year of a $10 billion request for research, development, test and evaluation (RDT&E). That amount is spread among six phases of R&D: basic research, exploratory development, advanced development, engineering development, management and support, and operational systems development.

Military R&D has a profound effect on the direction and size of the overall defense budget. Dr. Malcolm E. Currie, Director of Defense Research and Engineering, characterized RDT&E as a "highly leveraged activity." This leveraging occurs because the program area—a small fraction of the total defense budget—"directly influences the magnitude and effectiveness of much larger future expenditures." While the bulk of the cost for weapons systems is in production and for operation and support, those amounts are determined in large degree by RDT&E. From a budgetary standpoint, then, research and

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[1] *Special Analyses: Budget of the United States Government, Fiscal Year 1977,* at 281.

development may play the part of the camel's nose. Dr. Currie estimates that by the time the Pentagon commits itself to production it has spent less than 15 percent of the total system life cycle cost. And at the point it makes the key decision to move from research into engineering development, it has spent less than 3 percent of the total (2657). [To keep footnotes to a minimum, all references to the fiscal 1976 hearings by Senate Armed Services are placed in parentheses. The page numbers come from four separate volumes on the authorization bill, S. 920: Part 4 (pages 1709–2167), Part 6 (pages 2637–3605), Part 7 (pages 3607–4030), and Part 10 (pages 5123–5691).]

Until recent years, RDT&E was a "low visibility" item of the defense budget. Compared to procurement it attracted little attention and participation from Congress. Increasingly, however, Members of Congress became sensitive to the toehold gained by projects in the R&D stage. Once they ripen into a weapon system, funded through a procurement account, a constituency develops of such size and influence that it is difficult to terminate or curtail the program. A variety of arguments, including the need to keep the production line open, are offered to sustain programs at that point.[2] A much greater commitment of time and staff resources is now committed to the investigation of R&D by Senate Armed Services and the Senate defense appropriations subcommittee.

This paper concentrates on the procedure used by the Senate for evaluating, selecting, and authorizing military R&D programs. Thousands of individual research projects are involved; legislative resources are scarce. How does the Senate organize itself to pass judgment on issues that are—by their very nature—inescapably complex and technical? By what criteria do Senators decide whether a project should go forward or whether it should be terminated or curtailed? What changes might be made in the congressional review process?

The importance of procedural aspects has been highlighted by Senator John Stennis, chairman of the Armed Services Committee. As a lawyer by training, he concluded that the discussion of weapon systems by Congress was "sadly deficient in its understanding of persons and procedures." He compared it to an attempt to understand problems of law, order, and justice by focusing entirely on specific defendants. But issues of criminal law, he said, could not be understood without comprehending the procedures of arrest, indictment, arraignment, trial, and appeal. It was also necessary to consider "certain darker sides of the judicial process, such as plea bargaining and the possibility of corruption." By examining the procedures employed by the Pentagon, he hoped that Congress and the public would have a better understanding of the field of weapon system acquisition.[3]

This paper extends the inquiry to procedures used by the Senate. In order to treat the subject with the depth and care that it deserves, I focus primarily on the activities of a single Subcommittee: the Subcommittee on Research and Development of the Senate Armed Services Committee. Special programmatic issues, such as funding for Independent Research and Development (IR&D), are not covered. Nor

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[2] See, for examples, Craig Liske and Barry Rundquist, "The Politics of Weapons Procurement: The Role of Congress," The Social Science Foundation and Graduate School of International Studies, University of Denver, Monograph No. 1, 1974–75.

[3] *Weapon System Acquisition Process*, hearings before the Senate Armed Services Committee, 92nd Cong., 1st Sess., 1–2 (1971).

is there any treatment of the Tactical Air Power Subcommittee of Senate Armed Services, which handles part of the RDT&E authorization.

The R&D Subcommittee, headed by Senator Thomas J. McIntyre, has been the subject of considerable praise. Representative Les Aspin, observing that some committees and subcommittees take the lead or initiate new policy, cited the McIntyre Subcommittee as one example. During debate in 1971, Senator Peter H. Dominick, a Republican, commended Senator McIntyre for going into "extraordinary detail, in I think probably the most fruitful program we have had for a long time to delve into the enormous amount of money spent on research and development." Senator John Stennis, chairman of the Armed Services Committee, stated in 1974 that the effort by the McIntyre Subcommittee had been "the most complete and thorough and extensive hearing with reference to research and development concerning military weapons that any subcommittee or any committee of the Congress has ever held in covering an entire research and development program." [4]

In addition to the activity of the R&D Subcommittee, this paper explores the relationship between Senate Armed Services and Senate Appropriations. The important roles of the Senate Budget Committee and the Congressional Budget Office, presently in a formative and evolutionary stage, are not discussed. An introductory section provides historical material (for the period since 1959) to show how both Houses have expanded their roles and responsibilities for authorizing defense R&D.

This study is based primarily on a reading of hearings held by Senate Armed Services over the period from 1963 through 1975. Other hearings, committee reports, floor debates, General Accounting Office reports, and studies from the private sector are used to supplement the record. Interviews were held with 13 people from the following areas: Senate Armed Services (4); Senate Appropriations (2), personal staffs of Senators (3), and the Department of Defense (4). Discussions were also held with two former Senate staff members: William H. Darden, who served with the Armed Services Committee from 1951 to 1968, and Francis S. Hewitt, professional staff member of the Appropriations Committee from 1947 to 1974.

I. Introduction

Prior to 1959 congressional control over defense programs consisted of two steps: broadly drawn authorizations—available on a continuing basis—and passage each year of an appropriation act. To obtain funds the Defense Department had only to justify its detailed budget requests before the Appropriations Committees. The Armed Services Committees did not exercise annual, substantive control over weapons systems. Military construction represented one of the few areas in the defense budget to receive scrutiny at the authorization stage.

Matters changed, however, during the 1950s. A number of factors led Members of Congress to assume a more active role in strategic decisions. Dissatisfaction with the military establishment was one

[4] Les Aspin, "The Defense Budget and Foreign Policy: The Role of Congress," *Daedulus*, Summer 1975, at 168; 117 Cong. Rec. 42934 (Nov. 23, 1971); 120 Cong. Rec. S9486 (daily ed., June 3, 1974).

reason, especially in view of interservice rivalries over which missile to use for air defense. Experience with military construction had also given the Armed Services Committees important insights into weapon systems, for often they depended on acquisition of sites and construction of radar networks and control centers. Still another motivation was the desire of the House Armed Services Committee to compete on a more even basis with the defense subcommittee of House Appropriations. On the Senate side, where such friction was minimal because of overlapping membership between Armed Services and the defense appropriations subcommittee, the principal reason was more a feeling on the part of some Senators that annual review by Armed Services was required to satisfy Congress' responsibilities under the Constitution. Senate hearings on the Defense Reorganization Act of 1958 became a forum to air such views.[5]

Section 412(b)

What emerged from this ferment was Section 412(b) of the Military Construction Authorization Act of 1959. It provided that "No funds may be appropriated after December 31, 1960, to or for the use of any armed force of the United States for the procurement of aircraft, missiles, or naval vessels unless the appropriation of such funds has been authorized by legislation enacted after such date." [6] The requirement for annual authorization—initially restricted to procurement—would reach within a few years to research and development.

Intervention by Congress in weapons systems procurement provoked skepticism in many quarters. The authorization committees were identified with a narrow set of interests, although hearings by the Senate Armed Services Committee during the 1950s demonstrate activity not merely in military construction but also in manpower, military pay, management, missile programs, naval vessels, NATO Status of Forces Treaty, and procurement. Nevertheless, the Armed Services Committees were publicly associated with real estate matters—preoccupied with the location of installations and the purchase and sale of properties. Some Members of Congress also doubted their competence to decide issues of weapons systems. One was quoted as saying: "How the hell do we know what should be considered anyway? We mostly reflect what the military men tell us." [7] At the time of legislative debate on Section 412, the military commentator for the *New York Times* warned that Congress might "choose a weapon or a system on the basis of political and economic factors rather than on objective military and technical ones." [8]

Yet the Armed Services Committees had witnessed such duplication, agency infighting, and indecisiveness on the part of the Defense De-

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[5] Edward A. Kolodziej, *The Uncommon Defense and Congress, 1945–1963*, 369–74 (1966).

[6] P.L. 86–149, 73 Stat. 322 (1959). Background on Section 412 is provided by Bernard K. Gordon, "The "Military Budget: Congressional Phase," 23 *J. of Pol.* 689 (1961); Raymond H. Dawson, "Congressional Innovation and Intervention in Defense Policy: Legislative Authorization of Weapons Systems," 56 *Am. Pol. Sci. Rev.* 42 (1962); and Herbert W. Stephens, "The Role of the Legislative Committee in the Appropriations Process: A Study Focused on the Armed Services Committees," 24 *West. Pol. Q* 146 (1971).

[7] Lewis Anthony Dexter, "Congressmen and the Making of Military Policy," in *New Perspectives on the House of Representatives*, Robert L. Peabody and Nelson W. Polsby, eds. (1969), p. 185.

[8] Hanson W. Baldwin, *New York Times*, May 28, 1959, p. 13, cited in Dawson, *supra* note 6, at 53.

partment that it was untenable to believe that defense planners operated exclusively on objective military and technical factors. Moreover, in an article published just prior to enactment of Section 412, Roger Hilsman concluded that one of the more distinctive and noteworthy trends in Congress was the technical competence of its membership: "Among the more responsive and active members, there seem to be one or two for almost every major problem area who are just as knowledgeable as the specialists." He ventured that even the less responsive member could acquire more knowledge over his career of ten to fifteen years than a Secretary or Assistant Secretary who had been on the job for a year or two.[9] Beyond expertise there was the elementary political responsibility of Congress. Alton Frye has recently noted: "Granted that problems of military strategy and technology are immensely complicated and mind-numbing affairs, the root questions are ethical and political in nature." [10]

Enactment of Section 412, occurring at the time of a Democratic Congress and a Republican President, suggests a partisan flavor. But the impulse went far deeper. Congress, as an institution, sensed that its powers and prestige were in jeopardy. The practice of impounding defense funds, which had precedents under President Truman, continued under Presidents Eisenhower and Kennedy. In 1962 the House Armed Services Committee, after reviewing this development, rejected the notion that Congress should be restricted to a passive role in defense policy: "The committee finds it hard to believe that its extended and infinitely detailed hearings are designed only as an exercise in self-improvement in the area of *knowledge*. For knowledge is something to be used, not merely to be possessed." [11] And on this same page appears an admonition which is frequently quoted in the literature:

> To any student of government, it is eminently clear that the role of the Congress in determining national policy, defense or otherwise, has deteriorated over the years. More and more the role of the Congress has come to be that of a sometimes querulous but essentially kindly uncle who complains while furiously puffing on his pipe but who finally, as everyone expects, gives in and hands over the allowance, grants the permission, or raises his hand in blessing, and then returns to his rocking chair for another year of somnolence broken only by an occasional glance down the avenue and a muttered doubt as to whether he had done the right thing.

House Armed Services was particularly upset by the Pentagon's record on the B–70 (later redesignated RS–70) manned bomber. The committee believed that the bomber represented "such an important potential of our future offensive and defensive capability that its progress should receive as broad a congressional scrutiny as is possible in order to insure that this weapon system proceeds at a pace consistent with advances in technology and military requirements." [12] To accelerate development of the bomber, the committee took two steps. It "directed" the Secretary of the Air Force to use not less than $491 million during fiscal 1963 to proceed with production planning and long lead-time procurement of the RS–70. It also added to Section 412 the following provision: "no funds may be appropriated after

[9] "Congressional-Executive Relations and the Foreign Policy Consensus," 52 *Am. Pol. Sci. Rev.* 725, 725–26 (1958).
[10] Alton Frye, *A Responsible Congress: The Politics of National Security* 2 (1975).
[11] H. Rept. No. 1406, 87th Cong., 2d Sess., at 7. Emphasis in original.
[12] Id. at 3.

December 31, 1961, to or for the use of any armed force of the United States for research, development, or procurement of the RS–70 weapon system unless the appropriation of such funds has been authorized by legislation enacted after such date." [13]

In this way the committee extended the annual authorization requirement from procurement to R&D. The Senate Armed Services Committee proposed to make the requirement even more general to cover research, development, test, or evaluation of *all* aircraft, missiles, and naval vessels. That was consistent with the committee's original recommendations, in 1959, to require annual authorizations for design and development as well as procurement. The committee explained that in former times the weapons acquisition process involved a "relatively brief period of research and development, followed by long production runs." But the complexity of modern weapon systems had the effect of prolonging the research and development period and shortening the production period. And as weapon systems became more complex it became more difficult to separate development from production: "The latter stages of development and the early stages of procurement tend not to be susceptible to precise delineation." Committees with legislative responsibility considered it necessary to look not only at production but also research and development. As enacted into law, the 1962 provision extended annual authorization to any RDT&E associated with aircraft, missiles, and naval vessels.[14]

A year later the House Armed Services Committee, urging greater coverage, pointed out that of the $7 billion expended for defense RDT&E in each of the fiscal years 1963 and 1964, only about half related to aircraft, missiles, and naval vessels.[15] The committee therefore proposed that the annual authorization requirement be extended to *all* RDT&E. The Senate Armed Services Committee agreed and the requirement became law in 1963.[16]

R&D Subcommittee

Under the chairmanship of Richard Russell, the Senate Armed Services Committee met in full committee to consider procurement and RDT&E requests. The committee faced a very heavy burden. Defense Secretary Robert S. McNamara, during hearings in 1963, estimated that the R&D budget contained about 320 subactivities, which were aggregations of some 1,600 technical projects. Those projects, in turn, were aggregations of about 15,000 technical tasks. Dr. Harold Brown, Director of Defense Research and Engineering at that time, put the figure higher at some 20,000 work units.[17]

The record of Congress in discharging its Section 412(b) responsibilities led some observers to conclude that annual review of procurement and RDT&E authorizations had actually weakened the legislative role in national defense. Although annual review produced

[13] Id. at 1–2. For the eventual removal of the "directive" to the Air Force Secretary and the controversy over the RS–70 bomber, see Louis Fisher, *Presidential Spending Power*, 163–65, 307–08 (1975).

[14] S. Rept. No. 1315, 87th Cong., 2d Sess., at 2–3; P.L. 87–436, 76 Stat. 55, sec. 2 (1962).

[15] H. Rept. No. 345, 88th Cong., 1st Sess., at 15.

[16] S. Rept. No. 571, 88th Cong., 1st Sess., at 40. P.L. 88–174, 77 Stat. 329, sec. 610 (1963). See also conference report, H. Rept. No. 882, 88th Cong., 1st Sess., at 25.

[17] *Military Procurement Authorization, Fiscal Year 1964*, hearings before the Senate Committee on Armed Services, 88th Cong., 1st Sess., 235, 414 (1963).

more information for Congress, it accentuated the divisions within Congress, pitting authorization committee against appropriation committee. In the words of one analyst:

By stressing committee prerogatives and the question of what committee should make decisions, not what decisions should be made, Section 412(b) weakened congressional cohesion which is a prerequisite for the effective assertion of Congress' authority, especially in the face of growing centralization in the executive branch. The diffusion and dissipation of congressional power and authority were more pronounced in the House, where the armed services committee and the appropriations defense group drifted progressively apart. As a consequence, an already strong defense secretary strengthened his position before Congress. The armed services committees increased their prestige and influence over security affairs relative to the defense appropriations subcommittees since the inception of Section 412(b), but Congress' political power in these areas decreased vis-a-vis the President and the Secretary of Defense.[18]

During Senator Russell's illness in 1965, Senator Stennis served as acting chairman of the Armed Services Committee. Senator Stennis remarked that he had "always been intrigued" by the defense R&D program "but I never have been able to get into it to the extent I would like to." He appointed a temporary subcommittee to give additional consideration to that part of the defense budget. Senator Stuart Symington was named chairman of the six-member group: three from the defense appropriations subcommittee (Allen J. Ellender, Daniel K. Inouye, and Milton R. Young) and three from Armed Services (Margaret Chase Smith and Gordon L. Allott, in addition to Symington). The subcommittee was asked to complete its work within two or three weeks, prior to committee markup of the authorization bill.[19] From discussions with the staff members associated with that effort, apparently no written report was prepared.

When Stennis became chairman in 1969, he established a separate R&D Subcommittee headed by Thomas J. McIntyre. Senator McIntyre noted that the Subcommittee, from the beginning, recognized that it would be impossible to make a detailed examination of each of the thousands of line items in the R&D budget. Members of the Subcommittee concluded that it would be "more productive to structure our examination toward a testing of the decision-making process, and a probing for what we would call soft spots, for examples of interservice duplication or parallel developments, or for developments leading to the satisfaction of questionable operational requirements." [20] Two years later Senator McIntyre said that his Subcommittee was faced with about 500 line items in the budget request, each line item involving an average of three or four projects. This produced "a myriad of about 4,000 projects; we spend an awful lot of time, but we are lucky if we can take a look or have a briefing or hearing on, say, 15 percent of those projects." [21]

Legislation in 1973 codified the authorization language to make it a permanent part of Title 10, United States Code. With regard to RDT&E, the language now provides that funds may not be appropri-

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[18] Kolodziej, *supra* note 5, at 422–23.

[19] *Military Procurement Authorizations, Fiscal Year 1966*, hearings before the Senate Committee on Armed Services and the Senate Defense Subcommittee on Appropriations, 89th Cong., 1st Sess., 501–502 (1965).

[20] *Authorization for Military Procurement, Research and Development, Fiscal Year1970, and Reserve Strength* (Part 2), hearings before the Senate Committee on Armed Services, 91st Cong., 1st Sess., 1866 (1969).

[21] *Weapon Systems Acquisition Process*, hearings before the Senate Committee on Armed Services, 92d Cong., 1st Sess., 35–36 (1971).

ated for any fiscal year to or for the use of any armed force, or obligated or expended, for "any research, development, test, or evaluation, or procurement or production related thereto," unless funds have been specifically authorized by law.[22]

Under certain conditions a project, although lacking specific authorization, may nevertheless be funded by the Appropriations Committee. Senate Rule XVI, which contains a number of restrictions on amendments to appropriation bills, provides some opportunities for funding unauthorized projects. For example, Paragraph 1 of that Rule states that no amendments shall be received to any general appropriation bill the effect of which would be to increase an appropriation already contained in the bill, or to add a new item of appropriation, *unless* "the same be moved by direction of a standing or select committee of the Senate. . . ." The requirement "moved by direction" is satisfied when the Appropriations Committee reports a bill.

Technically, then, the Appropriations Committee is limited by two broad sets of criteria: the appropriation account must be authorized (e.g., a lump-sum amount for RDT&E/Navy), and the Committee may not exceed the dollar ceiling authorized for the account. Those two criteria do not reach to detailed projects included within the lump-sum amount and itemized in agency budget justifications or committee reports. Since the Armed Services Committee does not specify individual projects in its bill, the Appropriations Committee may fund an unauthorized project without doing violence to an authorization law. In 1975 the Senate Appropriations Committee added $5.1 million for the Enforcer close support aircraft, which had not been authorized by Senate Armed Services. This incident is explored more fully in Section III under the subheading "Relationship to Appropriations Committee."

The Armed Services Committee exercises control over individual projects by means of "nonstatutory controls"—language in committee reports and other portions of the legislative history. The Appropriations Committee is not legally bound by nonstatutory controls, nor are executive departments and agencies. As pointed out by the Comptroller General in a letter to Senator McIntyre: "Since the RDT&E appropriation is not a line-item appropriation, the amounts appropriated for each department . . . represent the only legally binding limits on RDT&E obligations except as may be otherwise specified in the appropriation act itself."[23] Recently the Comptroller General ruled that the Navy was not required as a matter of law to follow directives placed in a conference report. Agencies ignore such expressions of legislative intent "at the peril of strained relations with the Congress." The duty to abide by such expressions is practical, not legal.[24]

II. Departmental Presentation

Part of the Pentagon's presentation appears in the Defense Secretary's annual "posture statement" delivered to the full Armed Services Committee. That record is supplemented by separate briefings, unpublished studies, and the more specialized work of the subcommittees

[22] P.L. 93–155, 87 Stat. 612, sec. 803; codified as 10 U.S.C. 138. For legislative background see H. Rept. 93–383, at 86, and H. Rept. 93–588, at 39–40.

[23] 121 Cong. Rec., S8149 (daily ed. May 14, 1975).

[24] Decision of the Comptroller General of the United States, "LTV Aerospace Corporation," B–183851 (Oct. 1, 1975), at 22.

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within Armed Services. The quality of the presentation deteriorates when there is high turnover of agency personnel. Administrative officials, who have but a year or two at the job, must spend most of their time gaining a general orientation and acquiring basic knowledge about the programs and projects within their control. That leaves little time for analysis and independent inquiry. Dependence on military and civilian career staff is necessarily high. The maximum limit on career salaries in the executive branch, in place since 1969 and modified somewhat in 1975, has made it difficult for the Pentagon to recruit and hold the type of people it needs (1971, 3326).

For the past four to five years the Pentagon has made efforts to retain military project managers for longer periods of time. Previously, turnover was high among military personnel who found themselves temporarily assigned to the role of project manager. To enhance their career opportunities they preferred to move from one position to another, picking up experience and training in management, intelligence, command of troops, and other tasks. At the very point that they learned their job as project manager the assignment would end. Months would go by before a replacement filled the slot and comprehended the ongoing problems.[25]

Annual Posture Statement

The R&D Subcommittee experimented with a new approach in 1975. In previous years the question "Why do you need this?" often went unanswered because departmental witnesses were basically program managers or engineers. The Subcommittee had limited success in examining the specific details of the current and projected strategic threat, the quality of intelligence estimates supporting the threat assessment, and the relationship that existed between force levels and the threat.

To strengthen the Subcommittee's analysis of those areas—in more systematic and integrated fashion—hearings were held February 25, 1975 to listen to representatives from the strategic programs offices and the Defense Intelligence Agency. The need for a strategic nuclear deterrent was discussed solely in terms of the Soviet Union. As noted by one representative from the Defense Department, the People's Republic of China "does not pose a strategic military threat to the United States at the present time nor do we see any change of the status for the near future." Chinese nuclear forces did represent a threat to the Soviet Union (1711).

The Soviet threat to the United States was described primarily along the following lines: forces deployed, weapons performance, commitment of funds and human resources, and advances in science and technology. Mr. E. C. Aldridge, Jr., Deputy Assistant Secretary of Defense (Strategic Programs), warned the Subcommittee that the Soviets are "deeply committed to the advancement of science and technology. Accordingly the U.S.S.R. has allocated a greater share of its resources to military production R&D than any other world power" (1713). Director Currie, of Defense Research and Engineering, said that the Soviets were "working hard to change the technology balance by trying to gain initiative in many areas of military R&D" (2651).

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[25] Testimony by Gilbert W. Fitzhugh, chairman of the President's Blue Ribbon Defense Panel. *Weapon Systems Acquisition Process,* hearings before the Senate Committee on Armed Services, 92d Cong., 1st Sess., 45 (1971).

The extent of the Soviet effort has been questioned by other authorities. In testimony June 18, 1975, CIA Director William E. Colby discussed the difficulty of estimating Soviet military RDT&E outlays; analysis of that area was more difficult than for procurement or operating costs. Later in those hearings the Director of the Defense Intelligence Agency stated that the United States led the Soviet Union in almost all military technologies, although he expressed concern about certain areas such as the application of lasers. He also agreed that larger Soviet expenditures do not necessarily result in greater effectiveness.[26] Dr. Frederick Seitz, President of the Rockefeller University, offered these comments during an address to the General Accounting Office:

> I had the privilege recently of reading a document that was a translation not of a classified but of a somewhat privileged Soviet analysis of their own problems connected with their expenditures for science and technology. The issues which appeared in it were a complete duplication of our own. I think they're entering into a phase where they realize that they cannot double the expenditures for pure and applied science every five years without questioning quite carefully the way in which the money is spent.[27]

How does the Subcommittee determine whether the Defense Department is overstating the nature of the Soviet effort in military technology? Congressional distrust of Pentagon tactics is deeply ingrained. A particularly sharp critique, delivered by Senator McIntyre, identified the prime causes of public and congressional skepticism as the Pentagon's "incessant cry of wolf, their indiscriminate appeals to scare tactics, their unwillingness to do the difficult task of judging priorities. . . ." Senator McIntyre proceeded to rebuke the Pentagon for advocating "ill-conceived, indefensible, extravagant, and redundant programs on the basis of testimony which often lacks candor, accuracy, or even a decent respect for the constitutional status of the Congress of the United States." [28]

In an effort to evaluate the assertions of the Defense Department, Subcommittee staff will often check with outside sources, present those arguments to the Pentagon, and then go back to the outsiders with the Pentagon's rebuttal. A budget request can also be effectively analyzed by comparing different departmental statements in order to judge them from the standpoint of overall coherence, consistency, and integrity of the budget justification. The objective of the search is to build a more balanced and reliable picture—discovering "truth through triangulation."

Detente and Arms Control.—According to the Pentagon, the Soviet threat has not been alleviated by contemporary political accommodations. Detente, for example, was not a reason for the United States to reduce its R&D efforts in military weaponry. On the contrary, as "short-term tensions between the super powers may be eased, long-range technological and economic competition will persist and intensify. Renewed emphasis must be given to resources that we apply to long-term security" (2639). Neither did the Pentagon regard recent arms control agreements as a justification for cutbacks in military R&D. Because the Vladivostok agreement limited total numbers of

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[26] *Allocation of Resources in the Soviet Union and China—1975*, hearings before the Joint Economic Committee, 94th Cong., 1st Sess., 22, 31, 123–24 (1975).

[27] *Evaluating Governmental Performance: Changes and Challenges for GAO*, a series of lectures delivered at the United States General Accounting Office, 1973–1975 (Washington, D.C., Government Printing Office, 1975) at 191–92.

[28] 121 Cong. Rec., S18923 (daily ed. Oct. 29, 1975).

weapons and weapon carriers, the accord "re-enforces our need for technological progress. Evolution in performance of strategic systems will now be the decisive motivator on both sides as we seek further agreements" (2640).

Both arguments deserve careful scrutiny since they put the Pentagon in essentially a "never lose" position. Detente and arms control are given as reasons for increasing R&D efforts. What if detente were replaced by a more hostile political environmental and arms control gave way to an arms race? In such a case wouldn't the Pentagon also cite those developments to justify greater R&D spending? Whatever happens to those external variables, the result seems to be a request for additional funds. Apparently those variables are decidedly secondary and subordinate to the central test, which is the strategic value of weapons systems. As the Director of Defense Research and Engineering told the Senate Armed Services Committee in 1971: "if there were no Soviet threat, if there were no threat around the world, I would be the first to come in and ask this committee to reduce the research and development budget of the Department to zero."[29]

The claim that detente requires a "renewed emphasis" on technological competition is not elaborated in the Department's published justification statement. When Senator McIntyre asked why competition could not be eased, Dr. Currie replied: "I think that long-range competition is uncontrollable from our point of view. That is the world environment. . . . We are in a position of having to respond. We just don't have a choice in the matter" (2800).

The proposition that arms control requires greater R&D efforts received more attention. The request for funds for ballistic missile defense was justified in part as a hedge against sudden abrogation of the ABM Treaty (2704, 3234). But other Pentagon officials plan their budgets on the assumption that there will not be abrogation. Mr. Leonard Sullivan, Jr., Assistant Secretary of Defense for Program Analysis and Evaluation, told the House Committee on the Budget that his five-year budget projection was based on the assumption that there would be no abrogation of SALT agreements.[30]

Dr. Currie maintained that in an era of mutual restraints and arms limitation "we should continue to pursue promising technological options in our strategic programs both in order to preserve our capabilities and to encourage the Soviets to negotiate future arms limitations by convincing them of the futility of attempting to surpass us" (2693). Increased R&D might be a basis for cutting back on procurement, but that is only one of several possible scenarios. A larger budget for American R&D might also prompt the Soviets to increase their budget. It was this action-reaction phenomenon that former Defense Secretary McNamara singled out as the fuel behind an arms race.[31] On what basis does the Pentagon conclude that its scenario is the most likely? The public record is incomplete and unpersuasive on that issue.

Some commentators have argued that arms control is itself a stimulus for larger expenditures on R&D. It is suggested that the partial

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[29] *Fiscal Year 1972 Authorization for Military Procurement, Research and Development, Construction and Real Estate Acquisition for the Safeguard ABM and Reserve Strengths* (Part 1), hearings before the Senate Committee on Armed Services, 92d Cong., 1st Sess. 441 (1971). Statement by Dr. John S. Foster, Jr.

[30] *Force Structure and Long-Range Projections* (Part 1), hearings before the House Committee on the Budget, 94th Cong., 1st Sess., at 4 (1975).

[31] Robert S. McNamara, *The Essence of Security*, 58–59 (1968).

test ban treaty of 1963 and the SALT Agreement of 1972 made it necessary to "assauge domestic critics of these treaty agreements by promising a vigorous research and development program." [32]

Bargaining Chips.—The previous statement by Dr. Currie suggests a "bargaining chip" policy. R&D efforts are to be accelerated as a means of encouraging new constraints on weapons. But E. C. Aldridge, Jr., Deputy Assistant Secretary of Defense (Strategic Programs), told the Subcommittee: "We do not have, to my knowledge, any programs in our request that are called bargaining chips. All have strategic significance" (2145). This is ambiguous in the sense that bargaining chips themselves could be said to have "strategic significance." In fact, Dr. Currie later gave this advice to the Subcommittee: "while not readily admitted by defense witnesses, there is yet another complication in this problem involving the identification of options, formerly referred to as bargaining chips or SALT chips, those programs which primarily, if not solely, are to be traded away in our negotiations with the Soviets" (5123).

Different opinions exist within Congress as to the effectiveness of bargaining chips. Some Members suggest that congressional support of the Safeguard ABM system prompted the Soviet Union to agree to the 1972 limitations. Others reject that explanation. During a 1975 debate Senator Mondale maintained that it was congressional "misgivings and opposition" that led to a steady curbing of the ABM program: "That restriction, coupled with a realistic assessment on both sides about the limited value of ABM's, led to the agreement." [33]

In its report of September 1974, the Committee for Economic Development urged Congress to be "doubly cautious" about authorizing any defense system that is justified principally in terms of its bargaining value. The Committee stated that Congress could participate in such a process "only by letting itself be deceived, by deceiving its constituents, or by some congressmen deceiving others. There are certain diplomatic tactics for which the legislative branch of government in a democratic society is just not suited." [34]

Soviet Management

Deputy Assistant Secretary Aldridge identified centralization and vertical structure as the characteristics of the Soviet R&D system. While those features permitted the carrying out of high priority R&D programs, they also encouraged "some duplication and some wasted resources as each of the Ministries tries to be independent" (1714). Defense Secretary Schlesinger told the Senate Appropriations Committee in 1975 that Soviet reforms to centralize the R&D effort "have not as yet succeeded totally. Measures to tighten the interface between science, technology, and production continue to meet bureaucratic resistance." [35] This contradiction between centralization, on the one hand, and independent Ministries and bureaucracies on the other, has not been clarified by published hearings.

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[32] Harvey Brooks, "The Military Innovation System and the Quantitative Arms Race," *Daedalus*, Summer 1975, at 75.

[33] 121 Cong. Rec., S9422 (daily ed. June 3, 1975).

[34] *Congressional Decision Making for National Security*, at 35–37.

[35] *Department of Defense Appropriations, Fiscal Year 1976* (Part 1), hearings before the Senate Committee on Appropriations, 94th Cong., 1st Sess., 220 (1975).

Aldridge did note that the Soviets "follow a very rigid program in controlling the R&D practices and projections. They follow a procedure which allows them to only produce and assemble and to make weapon systems based upon proven technology. This then causes them to be rather slow and cumbersome in their approaches to developing new weapons" (1715). This Soviet approach was amplified later by Dr. Currie, who characterized the U.S. attitude toward defense R&D as a search for new technology or "quantum jumps." The thrust of the U.S. effort was to push back frontiers of technology, discover revolutionary solutions, stress innovation, and foster rapid change. By contrast, the Soviets practice a policy of "conservative incrementalism," encouraging step improvements of existing systems and components. Their policy was more evolutionary than revolutionary (2641). The Soviet system "seems to discourage real innovations, and despite what we perceive as large-scale development efforts, they frequently fall short of achieving what we accomplish with far less direct effort" (2652).

Later in the Currie statement, however, this distinction between the U.S. and Soviet systems of management began to fade. He said that U.S. technology base programs (creation of options) are "not aimed at exploring revolutionary concepts but are directed towards achieving incremental improvements in areas of well recognized and important need for improved military capability" (2682). He admitted that it was an "oversimplication" to characterize the U.S. approach as wholly quantum-jump oriented. Moreover, the Soviets were departing from their incremental approach: "They look at our system, see how productive it has been in the past, and in fact they are going down progressive, more innovative paths" (2782). To the House Appropriations Committee he remarked that in the last 4 or 5 years the Soviets, in the general R&D area, "have shown sharp shifts to a more quantum jump-oriented approach such as we have." [36] Precisely how the American and Russian management systems actually differ was never made clear.

Nor was it clear from the hearings whether "centralization" was an asset or a defect. The Currie statement described the Soviet military R&D system as "highly centralized, its priorities are the highest in the Soviet economy and its guidance and control come directly from the Politburo—about half of whose members have technical backgrounds" (2651). This would seem to underscore the nature of the Soviet threat.

But other statements, some already cited, suggest that centralization is not such an advantage. The Fitzhugh Report of 1970 warned that a "highly centralized decision-making process oriented to a single decision point, whether the decision point consists of one or two men, is inherently inadequate to manage the spectrum of activities required of the Department of Defense." [37] In 1972 the Director of Defense Research and Engineering (Dr. John S. Foster, Jr.) distinguished between two activities: "We are centralizing in the Office of the Secretary of Defense the direction and control of the intelligence activity and the telecommunications activity; but we are decentralizing the execution of

[36] *Department of Defense Appropriations for 1976* (Part 4), hearings before the House Committee on Appropriations, 94th Cong., 1st Sess., 544–45 (1975).

[37] *Report to the President and the Secretary of Defense on the Department of Defense*, by the Blue Ribbon Defense Panel, July 1, 1970, at 23.

the programs that have been approved." [38] The Pentagon has begun to provide in-house laboratories with "blockfunding" for greater management autonomy and responsibility (2648). The Pentagon's "Statement of Principles for Department of Defense Research and Development," with regard to program management, encourages delegation "wherever feasible" (2769). An assistant secretary told the R&D Subcommittee in 1975 that the Navy's research and development program depended not so much upon him as upon the "performance of the decentralized project manager organization to do the job" (2969).

Auxiliary Justifications

In addition to the threat from the Soviet Union, the Department of Defense put forth a number of other arguments to support its R&D budget request. The Currie justification statement in 1975 discussed events over the last year that signalled a world of changing leadership, power status and access to raw materials: "This requires that Defense R&D be broadly based and flexible so that it can produce options for unpredictable contingencies" (2639).

Although Dr. Currie stated that R&D programs were proposed "solely on their direct contribution to national security objectives," and that there is "no other purpose" for defense R&D, including "civil economic reasons," he wanted Congress and the public to understand that "an enormous civil bonus" resulted from defense R&D. The military effort had given impetus to such new industries as jet engines, computers, and nuclear power. The requirements of the Defense Department served to stimulate the "exploration and mastery of ever newer frontiers of technology" (2639). Later he reminded the Subcommittee that defense technology supported the "critical early development of many technologies that are now part of our everyday experience and important elements of our economic strength" (2672). That is a delicate argument, for to press the point too strongly can create the impression that the Soviet threat is insufficient to justify the entire R&D budget.

An alternate justification invoked the images of national pride and national character. In explaining the American ability to apply science to practical ends, Dr. Currie pointed to three characteristics: national style, incentives, and institutions. For the latter, the availability of both in-house laboratories and Federal Contract Research Centers served as links between the Defense Department and the universities and industry. Incentives were also important, for they offered pay and prestige to successful individuals and profits to corporations. But Dr. Currie's description of national style was particularly intriguing:

> Modern America evolved from a frontier society. The frontier today lies in science and technology, and Americans remain anxious to reach out and explore. We have a competitive society, and science and technology are highly competitive. Individual initiative is our hallmark. There is a boldness, a willingness to set high goals, to risk, and to be conspicuous—in a loss or a win—that has been part of our heritage and part of our education. There has evolved a basic confidence that investment in research and development, coupled to real needs in a competitive environment, will provide the edge—and it has (2640).

[38] *Fiscal Yar 1973 Authorization for Military Procurement, Research and Development, Construction Authorization for the Safeguard ABM, and Active Duty and Selected Reserve Strengths* (Part 2), hearings before the Senate Committee on Armed Services, 92d Cong., 2d Sess., 824 (1972).

Unless this passage is read narrowly to associate R&D to "real needs," it suggests technology for the sake of technology. In 1974 Dr. Currie emphasized that the R&D budget, in addition to being based on congressional perception of external threats, depended also on "the element of faith." He explained that science, technology, a sense of innovation, and an adventuresome spirit had, in the past, been key elements "in building the foundation for the past and for the present and I think it will every bit as much for the future. So in this respect your decisions in this committee are decisions of vision." [39]

This emphasis on technology is significant, since the strong support extended to scientific research (particularly after the launching of the Soviet Sputnik in 1957) shows signs of tapering off. In 1972 the Commission on Government Procurement reported that the latter half of the 1960s registered profound changes in attitudes toward R&D. Despite the successful manned lunar landing in 1969,

> . . . public disenchantment led to questions regarding the utility of costly defense and space endeavors especially in the presence of growing discontent and concern for social problems such as education, the environment, health, housing, and transportation. These changes in national attitude dampened the enthusiasm for basic research, academic science, and the training of scientific manpower in favor of increased attention to more immediate and visible goals in the public sector.[40]

Time magazine, in 1973, described the public's attitude toward science as one of "deepening disillusionment." [41] Dr. Frederick Seitz, President of the Rockefeller University, has observed that the trend since the mid-1960's has been to "downgrade the emphasis on science for its own sake or for its use in solving everyday problems." Scientific research in academic institutions had been most influenced by those changes, "but their effect runs deeply throughout our society, as anyone who attempts to raise funds for scientific research from private sources quickly learns." [42]

III. Congressional Review

In reviewing the Pentagon's request for fiscal 1976 and the July–September 1976 transition period, the R&D Subcommittee held informal briefings with departmental personnel prior to its regularly scheduled hearings. Field trips by committee members and committee staff were also arranged. Those efforts are supplemented by year-round contacts (phone or personal visits) between the Subcommittee and Pentagon officials. Correspondence from the committee can also be effective. For example, in 1973–74 the Senate Armed Services Committee was successful in slowing down the Navy's Surface Effect Ships (SES) program. Based on a GAO study, the committee was able to persuade the Department of Defense that it should not proceed with a prototype follow-on.[43]

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[39] *Fiscal Year 1975 Authorization for Military Procurement, Research and Development, and Active Duty, Selected Reserve and Civilian Personnel Strengths* (Part 3), hearings before the Senate Committee on Armed Services, 93d Cong., 2d Sess., 865 (1974).

[40] *Report of the Commission on Government Procurement*, December 1972, Volume Two, at 54.

[41] Cited in Amitai Etzioni and Clyde Nunn, "The Public Appreciation of Science in Contemporary America," *Daedalus*, Summer 1974, at 192.

[42] *Evaluating Governmental Performance: Changes and Challenges for GAO*, a series of lectures delivered at the United States General Accounting Office, 1973–1975 (Washington, D.C., Government Printing Office, 1975), at 182.

[43] S. Rept. 884, 93d Cong., 2d Sess., 106 (1974).

The committee schedule for calendar 1975 was particularly tight because of the new congressional budget process. Senator Stennis established the goal of May 15 for the full Armed Services Committee to complete action on the authorization bill. Consequently, the R&D Subcommittee had to report its recommendations to the full committee two weeks earlier than in the past.[44]

Regarding formal hearings, the Subcommittee met on sixteen separate days from February 25 through April 21, 1975. Except for March 19 and April 17, the Subcommittee met both morning and afternoon. Subcommittee chairman Thomas J. McIntyre was present for all but one of the thirty sessions: the afternoon of April 15, which was conducted solely by staff members. Attendance for other Subcommittee members ranged from fourteen sessions to two sessions. That was a marked improvement over previous years. In 1974, to provide one benchmark, the R&D Subcommittee met 35 times. On 24 of those occasions Senator McIntyre was the only member present; on no occasion was he joined by more than one Senator.

On days that Senators are present, other duties frequently cause them to come late to a hearing or leave early. The number of sessions attended, therefore, is not always the best measure of the number of hours invested. Yet Senators can also participate by submitting questions, having staff attend in their place, conducting field trips on their own, and other activities.

Multiple Committee Assignments

Infrequent attendance reflects the intense schedule that confronts each Senator. It has been estimated that the average Congressman spends one-fourth of each week on floor duties and another fourth on legislative research and responding to mail. Additional time is consumed by constitutent problems, visits with constituents, leadership or party functions, writing, meeting with lobbyists, and press work, radio and TV. That leaves 12 percent of each week for committee meetings and another 5.9 percent for committee work performed outside of committee.[45] Interviews on the Senate side suggest that approximately 20 percent (and probably less) of a Senator's week is available for committee work.

Staff assistance for the R&D Subcommittee in 1975 included Hyman Fine, staff director; Robert Q. Old, assistant to the two Republican members; George Foster, from the full committee staff; and Charles Cromwell, staff director of the Tactical Air Power Subcommittee which shares jurisdiction over R&D. Staff members from the Senators' individual offices also assist: Larry Smith for Senator McIntyre, Douglas Racine for Senator Leahy, Charles Stevenson for Senator Culver, and William Lind for Senator Taft. Mr. Smith has now joined the staff of the Armed Services Committee. Staff members from the Senators' individual offices estimate that 15–20 percent of their time is devoted to R&D Subcommittee matters. Mr. Smith, as assistant to Chairman McIntyre, spent considerably more time than that—as much as 50–70 percent of his year. In previous years only com-

[44] 121 Cong. Rec., S9196 (daily ed. June 2, 1975). Statement by Senator McIntyre.

[45] Study by John S. Saloma III, reprinted in *The Job of a Congressman,* Donald G. Tacheron and Morris K. Udall, second edition (1970), at 303–304.

mittee staff were permitted to attend hearings. Recently, however, staff members from Senators' offices are not only allowed to attend but invited to ask questions of Defense Department witnesses when their Senator is absent.

The workload problem for Senators is aggravated by multiple committee assignments. One hundred members of the Senate have to do the work of 435 members of the House. For the first session of the 93d Congress, House members filled 2,452 committee and subcommittee slots—an average of 5.6 per member. Senators filled 1,585 slots—an average of 15.9 per member.[46] With respect to the particular assignments of R&D Subcommittee members—counting committees and subcommittees—Senator McIntyre had fourteen assignments in 1975, Senator Culver six, Senator Leahy six, Senator Taft nineteen, and Senator Goldwater eight. A number of those assignments are to subcommittees that meet infrequently or not at all.

Opinions differ on the value of multiple subcommittee assignments. The practice results in sparse attendance at hearings, inadequate probing of agency testimony, heavy dependence on committee staff, and representation at many hearings of only one part or one philosophical point of view. The number of subcommittees could be reduced, as well as the number on which any Senator must serve. However, as Senator Muskie has noted, that "would also tend to narrow the areas in which he works, and thus narrow the horizon within which he works creatively."[47] In its report of June 1975, the Murphy Commission concluded that hearings and preliminary action by even two or three interested Senators in subcommittee "may be preferable to less frequent and detailed deliberations at the full committee level. In short, despite practical limitations, particularly in the Senate, active subcommittees can increase both the scope and depth of Congressional consideration of foreign policy matters."[48]

Terminating Programs

Faced with thousands of individual research projects and an ever-demanding schedule, how do Senators on the R&D Subcommittee decide where to focus? On what part of the budget request do they concentrate? With what success are programs of low priority terminated? The importance of programs of a relatively small size is borne out by figures released by the House Armed Services Committee. For fiscal 1975 there were 503 R&D programs that were less than $25 million each. Yet they totaled $4.9 billion, or more than half the budget request.[49]

The capacity of small R&D projects to blossom into big ones is especially troublesome when the Pentagon finds it difficult to terminate projects. The Senate Armed Services Committee observed in 1971 that the "record is replete with examples of parochialism among the Services, unwarranted duplication of weapons system developments, and

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[46] Charles O. Jones, "Congressional Committees and the Two-Party System," *Committee Organization in the House*, House Select Committee on Committees, 93d Cong., 1st Sess., Volume 2 of 3, Part 3 of 3, at 568.

[47] Senator Edmund S. Muskie, "Committees and Subcommittees in the Senate," in *The Senate Institution*, Nathaniel Stone Preston, ed. (1969), at 125.

[48] *Commission on the Organization of the Government for the Conduct of Foreign Policy*, June 1975 (Washington, D.C.: Government Printing Office), at 206–207.

[49] *Military Posture* (Part 4), hearings before the House Committee on Armed Services, 94th Cong., 1st Sess., 3735 (1975).

the non-productive perpetuation of research and development efforts which finally result in major program terminations and waste of research and development dollars." [50]

In a major address in 1974 before the Electronics Industries Association, Senator McIntyre expressed the need for greater selectivity in defense R&D, since a program "once initiated becomes most difficult to stop or substantially alter. It picks up momentum with each step in the R&D cycle. A service, or elements within a service, develop vested interest in programs deriving from R&D beginnings. So do you in industry. So do we in Congress." Although the McIntyre Subcommittee supported the maintenance of a strong technology base (research and exploratory development), it found that such efforts progressed to advanced development under the notion that the move was "tentative." Then Congress is advised that laboratory development has reached its limits; advancement to engineering development is necessary to see if component technology can be integrated into a system. Soon the program is on its way toward pre-production copies and deployment. Although the Subcommittee may be told at each stage that options are open and that no commitment has been made, it is difficult to cancel a program after hundreds of millions of dollars have been invested.[51]

Terminations should be frequent in the high-risk ventures of military R&D. Dr. George H. Heilmeier, Director of the Defense Advanced Research Projects Agency (DARPA), told the Subcommittee that if it wanted a research organization to push technological frontiers, achieve breakthroughs, and make quantum jumps, the organization needed the "freedom to fail." Defense Secretary Schlesinger had given him this advice: "Heilmeier, if you are too successful, I am going to think you are not doing your job because you are not pushing the frontiers hard enough." The Defense Secretary had talked about a 10-percent probability of success (3322).

DARPA is a particularly high-risk enterprise, but Group One programs (selection and demonstration of options) were also described by the Pentagon as "often risky—but payoffs from success are great. There will be—and should be—failures . . ." (2642). Congressman George H. Mahon offered this perspective on defense R&D: "Of course, there are many instances where we spend money on research and do not get any valuable return, but that is a gamble you have to take in some cases." Dr. Currie agreed: "You know, research and development by its inherent nature is sometimes speculative. It is not a sure thing." [52]

If RDT&E is by its nature a high-risk operation, why are there so few terminations? The record shows that it is difficult, in practice, for DOD to cancel an R&D project. Dr. Currie admitted that there were "institutional pressures" (military services) that made it difficult to cancel R&D programs. Marginal programs may be perpetuated as a result of industry pressures applied within Congress as well as within the Office of the Secretary of Defense and the Services (2796–2797).

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[50] S. Rept. 359, 92d Cong., 1st Sess., 85 (1971).

[51] 120 Cong. Rec., S7340–43 (daily ed. May 8, 1974). As one study notes, if Members of Congress conclude that an R&D project may move inexorably into production, they may be reluctant to see the project started at all. *U.S. Military R&D Management*, Special Report Series: No. 14 (The Center for Strategic and International Studies, Georgetown University, 1973).

[52] *Department of Defense Appropriations for 1976* (Part 4), hearings before the House Committee on Appropriations, 94th Cong., 1st Sess., 539 (1975).

Senator McIntyre commented on the fact that "you get one brigadier general, one congressman, on an R&D program and just try to turn that son of a gun off. You cannot do it." That was a problem not only in advanced R&D but in more junior programs as well (3322).

Search for Substantiation

After the protracted struggle in 1969 and 1970 over the Safeguard ABM system, with the principal challenge coming from the Senate, review hearings by the Senate Armed Services Committee revealed a firmer and more resolute tone. During hearings in 1971 Senator Stennis warned officials from the Defense Department: "I know a long time you were able to justify $7 or $8 billion worth of what is roughly called research and development and evaluation by just talking about the importance of research in general terms and you got those billions of dollars. I do not think you will be able to do that much longer . . . I think some year, maybe this year, you will be riding for a fall on this thing." [53]

During the 1975 hearings, when the Pentagon relied on assertions and claims without supporting documentation, members of the R&D Subcommittee pressed for evidence. For example, the DOD justification statement claimed that Soviet air and missile defense R&D efforts indicated that they intend to upgrade their defensive forces: "The overall magnitude of their R&D effort causes us concern because our efforts in this area are to [sic] austere in comparison" (2703). A staff member asked what was the quality of Soviet ballistic missile defense today and how did it compare with the Safeguard system. Dr. Currie replied: "I don't know." In a statement provided for the record, the Pentagon concluded that "our uncertainties as to the purpose and precise nature of these activities precludes any firm determination of the size of the total Soviet ABM R&D effort" (2871–2872). Another statement for the record estimated that the United States was not ten years ahead of the Soviets in ballistic missile defense technology and it was "entirely possible that we are not five years ahead." It was felt that the Soviets had a stronger resolve to develop and test BMD systems (2873). As refined by those remarks, the original statement has an abrupt and stark quality.

Also jarring was the statement that continuation of Soviet naval growth into the 1980s "could result in Soviet domination of all sea lanes" (2944). Senator Leahy asked whether that meant that the Soviets would determine whether other countries could use the sea lanes. Mr. H. Tyler Marcy, a new Assistant Secretary of the Navy, had difficulty in formulating a reply:

> The point I am trying to make, inasfar as the research work is concerned, this programmatically, what dominates our thinking is not so much force balance or maritime balance of numbers of ships as such, but if you will, the competitive strengths and weaknesses of our situation this would be true in almost any enterprise. That is what we try to concentrate on.
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> And I do not pretend to be an amateur admiral with 6 months in Washington responding to balance questions, which is why I would like to ask the admiral to speak (2964).

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[53] *Fiscal Year 1972 Authorization for Military Procurement, Research and Development, Construction and Real Estate Acquisition for the Safeguard ABM and Reserve Strengths* (Part 1), hearings before the Senate Committee on Armed Services, 92d Cong., 1st Sess., 323 (1971).

Senator Leahy pressed for an answer as to how the Soviets would dominate the sea lanes: "How would they go about doing it? Is it just because they are in a situation where commercially they can offer better deals, or is it going to be an out and out military thing where they say these sealanes shall be used only by Soviet approved ships?" Vice Admiral Moran, backstopping for the Assistant Secretary, responded to Senator Leahy: "you ask fine questions. How you exercise control of the sea is a question that is just very difficult to answer" (2965).

Senator Culver challenged the scenario of Soviet dominance of sea lanes. He told Assistant Secretary Marcy that the United States had elected to build fewer, more costly, more sophisticated ships. The Pentagon then used the disparity in numbers to try for budget increases. "Now look it," said Senator Culver, "you get awfully tired of arguing first quality and then quantity, and then asymmetrical, and then symmetrical, and then we are not interested in arithmetic, and then we really are, and you know, it just gets kind of tiresome." After Senator Culver had raised some additional points regarding political developments, force balance, and strategic options. Admiral Moran remarked that "you asked a few questions which are beyond the normal ken of research and development organizations" (2967). That reply also disturbed Senator Culver, for the Pentagon seemed to want it both ways. As Senator Culver noted: "I always find that research and development types are very willing to talk about the Soviet threat . . . they are very willing to talk about how big and bad the Russians are, but suddenly when we ask you a question, to say, all right, measure it against our corresponding capabilities, you say woops, sorry, that is not within my jurisdictional preserve. We had better wait for these force structure experts" (2968).

Relationship to Appropriations Committee

Prior to 1969 the relationship between the Armed Services Committee and the defense appropriations subcommittee was unusually close. Richard B. Russell chaired both committees, from 1963 through 1968, while Leverett Saltonstall was ranking minority of both Armed Services and the defense appropriations subcommittee from 1959 through 1966. During this period the two committees experimented with forms of coordination and cooperation. From 1964 through 1967 the committees held joint hearings. Senator Russell hoped that the procedure would expedite congressional consideration of the defense program and "avoid unnecessarily repetitious hearings," both for witnesses and for members of Armed Services and the defense appropriations subcommittee.[54] That approach was abandoned, in part because it left insufficient time for questioning by Senators. Another effort to link the two committees was the part played by William Woodruff, a member of the Appropriations Committee staff, who sat in on hearings by the Armed Services Committee in 1968 and 1969.

When Senator Russell became chairman of the full Appropriations Committee, in 1969, he gave up the chairmanship of Armed Services, following the Senate custom of not chairing more than one standing

[54] *Department of Defense Appropriations, 1965*, hearings before the Senate Committees on Armed Services and Appropriations, 88th Cong., 2d Sess., 1 (1964).

committee.[55] During his two years as chairman of the Appropriations Committee (and of the defense appropriations subcommittee), there remained a close linkage between the Appropriations and Armed Services Committees.

Allen J. Ellender became chairman of Senate Appropriations in 1971, chairing also the defense appropriations subcommittee. Since Senator Ellender had never served on Armed Services, the relationship between the two full committees was now different. Coordination between the two committees was helped by some overlapping of membership. Senator Stennis was third ranking member of the defense appropriations subcommittee. Senator Margaret Chase Smith, member of Armed Services, was second ranking minority on the defense appropriations subcommittee. Moreover, three members of Armed Services sat on the defense appropriations subcommittee as "ex officio" members: Senators Stuart Symington and Henry M. Jackson (for the majority) and Strom Thurmond (for the minority).

As a result of the Legislative Reorganization Act of 1970, overlapping membership on major committees is now being phased out. A "grandfather clause" protected Senators who enjoyed dual status on the following committees: Appropriations, Armed Services, Finance, and Foreign Relations.[56] When Margaret Chase Smith left the Senate, John Stennis became the only Senator with dual membership on Appropriations and Armed Services.

The relationship between Appropriations and Armed Services changed substantially after 1971. During debate that year on the defense appropriations bill, Senator McIntyre offered an amendment to restore most of what the Appropriations Committee had cut from military R&D. The Committee had pared the R&D budget by $112 million, leaving to the military services considerable discretion as to how to allocate the cuts. Senator McIntyre said that "to reduce the budget request by a lump sum amount is unwise. It may be interpreted as sidestepping to a degree the need to examine the details of the major programs so that specific reductions can be made where and when supported by the facts. It may also be interpreted as relinquishing to the Department of Defense the responsibility for deciding how to spread the reduction." [57]

Senator McIntyre explained that his own R&D Subcommittee had once undertaken to make percentage cuts that were "entirely judgmental and arbitrary." When the full Armed Services Committee asked the Subcommittee why a given percentage was selected, and why it could not be twice that, or half that, the Subcommittee found itself in an untenable position. Thereafter the Subcommittee attempted to cover the major part of the budget in detail. "As a consequence," said Senator McIntyre, "we were able to come up with specific recommendations by individual programs right down the line, and they were sustained by the full committee and the Senate as a whole." [58]

A dialogue between Senators McIntyre and Ellender illustrates some of the friction between the authorizing and appropriating committees.

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[55] This custom became a matter of Senate Rules as a result of the Legislative Reorganization Act of 1970 (P.L. 91–510), sec. 132(f), 84 Stat. 1166–67. This is now incorporated as part of Senate Rules XXV, paragraph 6(f).

[56] P.L. 91–510, sec. 132(e), 84 Stat. 1166. Incorporated as Paragraph 6(e) of Senate Rule XXV.

[57] 117 Cong. Rec. 42933 (Nov. 23, 1971).

[58] Id.

Senator McIntyre wanted to know why the R&D reduction was not $56 million, or one-half of the $112 million. "What is the logic," he asked, "that stands behind the $122 million?" Senator Ellender replied that it was the Committee's intention to accomplish a $500 million reduction, with part of that allocated to R&D. The McIntyre amendment was subsequently adopted by a vote of 53–33.[59]

In 1974 the Senate Appropriations Committee cut the defense R&D budget by $933.2 million, which was 10 percent of the $9.3 billion requested. The Pentagon provided Senator McIntyre with a list of 38 items representing high priority technology programs to be restored to the bill. On the basis of that list Senator McIntyre offered an amendment to restore $94.1 million in R&D funds. After receiving assurance from Senators McClellan and Stennis that the items would be given serious consideration in conference committee, Senator McIntyre withdrew his amendment.[60]

The general practice has been for the Senate Appropriations Committee to provide funds for individual programs and projects only after they have been authorized by the Armed Services Committee. As Senator Stennis noted in 1974: "The Armed Services Committee has insisted all the way through that matters should not be appropriated for unless they have been expressly authorized. Not all Members of Congress agree with that position, but I think it is a sound one. . . ." [61]

An exception to that practice occurred in 1975 when the Appropriations Committee provided $5.6 million to conduct a flight test of the Enforcer close support aircraft. Armed Services had held hearings on the aircraft, but only after the Senate had completed action on the authorization bill.[62] Senator Goldwater offered an amendment to delete the $5.6 million from the bill. Senator Cannon, a cosponsor of the amendment, expressed the view that while authorization of the Enforcer may not be required in a technical sense "it surely violates the spirit of the authorization process. In fact, Mr. President, if the Enforcer funding is allowed to remain in the bill, it will set an unmanageable precedent because everyone with enough political clout will use that precedent as justification to have included in future appropriation bills their favorite something-or-other." In a letter to their colleagues, Senators Cannon and Goldwater maintained that the addition of the $5.6 million violated the "established practices and procedures of the authorization and appropriations process." The Goldwater amendment was accepted 56–32. Eleven members of the Armed Services Committee voted for the amendment, four voted against it, and one did not vote.[63]

IV. Conclusions

Members of the Senate Armed Services Committee have spoken openly of their need for additional assistance. During hearings in 1969 Senator Barry Goldwater stated that the Committee lacked time to scrutinize Pentagon requests: "We need help on it." [64] Staff members

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[59] Id. at 42935.
[60] 120 Cong. Rec. S15521–S15526 (daily ed. August 21, 1974).
[61] 120 Cong. Rec. S9486 (daily ed. June 3, 1974).
[62] S. Rept. 94–446, at 259. *Enforcer Aircraft,* hearing before the Senate Committee on Armed Services, 94th Cong., 1st Sess. (1975).
[63] 121 Cong. Rec. S19906–20003 (daily ed. Nov. 13, 1975).
[64] *The Military Budget and National Economic Priorities* (Part 2), hearings before the Joint Economic Committee, 91st Cong., 1st Sess., 471 (1969).

who presently assist the R&D Subcommittee speak candidly of the frustration they feel in trying to discover an adequate handle to analyze budget requests.

Frequently it is proposed that Congress acquire additional staff capability. CED, for example, recommends that Congress establish an office to assist in the review of the defense budget and weapons programs.[65] Such proposals are received skeptically by the congressional staff presently responsible for defense authorizations. Recent years have brought a dramatic increase in legislative staff, including the greatly augmented responsibilities of the General Accounting Office and the Congressional Research Service, the new Office of Technology Assessment, and the resources available from the newly created Budget Committees and the Congressional Budget Office. The feeling runs deep that Congress, at least for the time being, has reached a saturation point.

Assistance at this point must come in a form that eases the burden and simplifies the task. Whether studies are conducted by existing staffs, a new permanent office, or a temporary commission, there must be appreciation and sensitivity for the intense schedule that already presses upon congressional committees. While the number of reports and analyses may climb without limit, the day remains fixed at 24 hours.

Program-Manager Role

The annual authorization procedure, by immersing the Armed Services Committees in a welter of detail, stands the risk of obscuring some of the larger policy questions that Congress is called upon to resolve. A step in simplifying the annual review was taken by the Pentagon in its fiscal 1976 budget, which organized R&D programs into two groups, each having separate objectives: (1) Group One represents the creation and demonstration of options which may be useful for future military capabilities; (2) Group Two consists of full-scale system development for potential deployment. Group One, composed of thousands of individual projects, amounted to a fiscal 1976 investment of roughly $4 billion. Group Two, with only a few hundred programs, totaled about $6 billion. The Pentagon considers the advancement of a program from Group One to Group Two as a crucial commitment.

The Pentagon invited the Subcommittee to examine the programs from this two-tier perspective, reviewing Group One programs in a broad sense rather than element-by-element. Detailed consideration by the Subcommittee was to be given only to programs in Group Two (2642–2643, 2659–2662). When a staff member of the R&D Subcommittee questioned the policy of excluding Congress from a close inspection of Group One programs, Dr. Currie said that his statement might be subject to misinterpretation and "could have been stated better." A number of programs were not "cleanly in one category or the other" (2810).

The R&D Subcommittee is often preoccupied by program-manager details that should have been resolved earlier at the departmental and agency level. How can such details and decisions be pushed back to

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[65] Committee for Economic Development, *Congressional Decision Making for National Security*, September 1974, at 24.

program managers to allow the Subcommittee to focus more on broad policy and strategic considerations? What might be done to create a system of incentives to encourage more realistic agency estimates and to instill a deeper sense of accountability and responsibility in program managers?

Errors—even of substantial magnitudes—are likely to occur in any budget estimates. If it was merely a matter of technical predictions, errors should fall in some random pattern: some high, some low. But both the competing contractors and the military services are motivated to put forth low cost estimates in order to win approval from Congress. A track record for an agency could indicate the extent to which Congress was being misled from year to year.

For example, the General Accounting Office prepared a five-year record of certain estimates of the Agency for International Development. Each year, when A.I.D. came before the Congress to request new funds, the Appropriations Committees would ask how much the agency expected to receive in the form of "recoveries" (funds that are tied up or committed but later made available for agency use). GAO found that over a five-year period actual recoveries came to $435.3 million rather than the agency estimate of $235.5 million. A.I.D. therefore had access to $181.2 million more than Congress had anticipated.[66] Once a picture like that develops, Congress is in a position to appropriate less new money and let the agency depend to a greater extent on recoveries.

Is it feasible or worthwhile to apply some type of five-year record to R&D agencies? On the basis of a track record the Subcommittee could correct for biases that appear in agency budget presentations. After recomputing to establish the more likely characteristics of the program, the committee may conclude that it be scrubbed, curtailed, or approved with full awareness of probable costs. Subcommittees operate on that basis today, but the record is often in the minds of Members of Congress and staff assistants. Preparation of a more regular and explicit record would give authorization and appropriation committees, as well as individual Members of Congress, a more complete data base to judge the merits and dimensions of a program request.

This record would not duplicate Selected Acquisition Reporting (SAR), which consists of quarterly reports from the Pentagon on major programs under full-scale development. Nor would it duplicate GAO's monitoring of cost increases for major weapons systems; GAO bases its product on the SARs.[67] SARs are insufficient in number (about 50) to penetrate sufficiently deep into the defense structure to spotlight agency performance. They track programs too late in their development (basically Group Two programs), and in some cases fail to include programs that have estimated costs in excess of a billion dollars.[68] Furthermore, termination of SAR reporting usually takes place when production is 90 percent complete. In contrast, a 5-year

[66] *Foreign Assistance and Related Programs Appropriations* (Part 2), hearings before the Senate Committee on Appropriations, 93d Cong., 1st Sess., 1524 (1973).

[67] See General Accounting Office, "Status of Selected Major Weapon Systems, Department of Defense," B–163058 (May 31, 1974).

[68] General Accounting Office, "How To Improve the Selected Acquisition Reporting System," Department of Defense, PSAD–75–63 (March 27, 1975), at 8. GAO states that LAMPS (Light Airborne Multipurpose System) was approved by the Navy in September 1973. As of June 30, 1974, LAMPS was not on SAR even though the estimated program cost was $1,572.8 million.

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track record would want to retain such programs in order to evaluate agency performance. A different vehicle is needed to influence agency behavior and alter the decision-making process. Congress would have to establish boundaries. With thousands of research projects there would have to be some threshold to determine what part of an agency's operation merits review.

Depending on the response by Congress to an agency's track record, budget estimates might become more realistic and reliable in order to earn the confidence of review committees. It is felt that program managers, by having to prepare SARs, are made more sensitive to cost growth. That should affect the relationship between agencies and contractors, for both would stand to win or lose on the basis of the integrity and credibility of budget estimates. A track record could thus have a self-policing quality. It might also be a vehicle for additional analysis, for the disparity between the performance of different organizational units, or between military services, would prompt investigation as to why some units fare better than others.

A number of difficulties, of one form or another, can be anticipated. Agency heads, particularly when turnover is high, may attribute an unattractive record to the shortcomings of their predecessors. The committees will probably be told that new agency regulations, recently promulgated, can be expected to prevent a repetition of such problems in the future. Yet Congress can insist that the evidence most persuasive is not promise but the proven record.

Fall Hearings

The R&D Subcommittee will always be involved in some details of program management. The Chairman has to defend the authorization bill when it reaches the floor. He must anticipate questions and critiques of the various programs. It is essential that he demonstrate to his colleagues that he has done his homework, for otherwise he is vulnerable to selective cuts or across-the-board reductions. Moreover, publicity in the press concerning cost overruns or poor performance will push the Subcommittee into program-manager issues. The tight schedule of the new congressional budget process also puts a premium on time, making it difficult for the Subcommittee to reach beyond individual programs to explore fundamental questions of need and purpose.

To supplement the spring hearings on the annual authorization bill, the Subcommittee could schedule fall hearings on a regular basis to examine broad issues. The Senate Armed Services Committee did that in 1971 when it held hearings on "Weapon Systems Acquisition Process."

Fall hearings could concentrate on fundamental questions: How do R&D programs relate to defense strategy and foreign policy objectives? Is there enough information to conclude that Soviet R&D expenditures are at a level equal or greater than ours? If we know what the Soviets are spending, how much of that effort is ineffective because of managerial inefficiencies? How much of it is directed not against the United States but against the People's Republic of China? What part is defensive in nature and not a threat to the United States? Are bargaining chips effective? Will heavy expenditures for R&D en-

courage arms control limitations with the Soviets or trigger an arms race? What portion of "inflation costs" are controllable by better management practices? What factors keep alive research projects that should have been terminated at an earlier stage? How often are contracts modified not for essential performance needs but to relieve contractors of financial difficulties?

While fall hearings could be useful for exploring issues that were left hanging and unresolved from the spring, other events are likely to compete for the time of Senators. During the fall of 1975, for example, the financial crisis of New York City commanded the attention of Senator McIntyre, a ranking member of the Banking, Housing and Urban Affairs Committee. And since fall hearings are not required—like the spring hearings on the annual authorization bill—it will be difficult to establish a high priority for them unless committee members are convinced that they serve a pressing and urgent need.

SOME OBSERVATIONS ON THE EFFECTIVENESS OF FEDERAL CIVILIAN-ORIENTED RESEARCH AND DEVELOPMENT PROGRAMS (FC/R. & D.)

By Albert H. Rubenstein *

CONTENTS

1. Introduction

This paper is an attempt to address a significant and perennial issue in the field of science and technology policy—whether we are getting our money's worth from the research and development (R. & D.) programs conducted by U.S. Federal civilian agencies. This is, of course, a complex issue which defies direct, simple measurement and evaluation. It is, however, one on which many opinions are expressed continually. My viewpoint is that of an active participant in research and consulting and direct involvement in the R. & D./Innovation (R. & D./I) process for many years. My special interest in this field is described briefly in the note of section 6.[1]

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[1] See section 6, p. 59.

The mode of exposition in this paper includes: Statements of some of the key issues related to the sub-areas of the topic identified by the Library of Congress staff; observations on what we know or strongly believe about these sub-issues; and suggestions for further analysis that is needed for effective policy-making and legislative action.

2. Measuring the Effectiveness of Federal Civilian-Oriented R. & D. Programs

Since the measurement and evaluation process is so complex and is likely to be expensive, we should be sure of our reasons for attempting it. Even in the private sector, where cost/benefit thinking dominates most decisionmaking, there are mixed motives for attempting to measure the output of R. & D. Some managers sincerely want to improve the R. & D. process by adjusting its organizational characteristics, the resources provided to it, the tasks assigned, the people provided, the mechanisms for selecting and evaluating particular projects and programs, and the procedures for getting products and processes out the lab door and into the market and the factory quickly and economically. Others are primarily curious and only want a superficial evaluation. Still others have an axe to grind, such as showing that R. & D. is not doing its job and that their activity (e.g., marketing or production) is not to blame for unsatisfactory sales volume, market share, new products, profits, or growth. Motivations such as the latter are not particularly useful for policy making and improving the overall R. & D./I process, because of the atmosphere under which they often exist. They can lead to defensiveness and obfuscation of the real weaknesses in the process, which may include: poor coordination between functional areas such as R. & D., marketing, and production; poor policy guidance by top management; lack of clear cut goals for R. & D.; or inadequate resources to do the job.

There are many parallels in federal civilian-oriented R. & D. to the situations described above for industry. The are further complicated by the political and administrative processes of government, the time lags in developing and implementing federal programs, the diffusion of responsibility and ability to take decisions and initiate action, the unclear and overlapping missions of potentially competing agencies, and other factors particular to the public sector. If there is a clear need and will to perform evaluations of the output of FC/R. & D. for purposes of legislation, policy formation, resources allocation, monitoring the R. & D./Innovation process, goal adjustment, operating procedures, or organizational arrangements, then I can say with confidence that some better methods of measurement and evaluation are available and developable than have traditionally been used.

At the outset of the attempts to measure, it is important to distinguish between two types of output from federal R. & D. programs, whether they are intended to be "civilian oriented" or not. The first relates to the prime mission of the agency or the particular R. & D. program within an agency—the "direct mission-oriented" outputs—and the other relates to "indirect, or spinoff" outputs. The prime missions of agencies dealing with such fields as: Education, law enforcement, atomic energy, transportation, health, and commerce are generally directed at particular sectors of the economy or society and their major outputs or impacts are sought in those particular areas.

Other Federal R. & D. efforts are more diffuse (e.g. space, energy in general. National Science Foundation) and it is not clear exactly in which areas to look for direct benefits.

Figure 1 [2] suggests the general problem encountered in attempting to directly measure the effectiveness of R. & D. in any sector, but particularly in the civilian sector of federally supported R. & D.

The framework of figure 1 contains five major "stages" in the relationship between inputs to R. & D. and ultimate measures of social and economic benefits. This highly simplified flow model considers a number of levels of output:

Immediate outputs (box 2) are direct outputs of the R. & D. process. They are claimed by R. & D. practitioners as being the direct result of R. & D. activity. These outputs appear close, in time, to the performance or completion of an R. & D. activity (e.g., a report, publication draft or patent application).

Intermediate outputs (box 3) are those immediate outputs incorporated as inputs to a social sub-system (e.g.. new drugs or new diagnostic techniques accepted for potential usage by the Health Care subsystem).

Pre-Ultimate outputs (box 4) are the recognized outputs of a social sub-system which, at least partially, may be attributed to the previous absorption of the intermediate outputs (e.g.. cure of certain diseases in patients processed through the Health Care sub-system and attributed to the use of the new drugs or diagnostic techniques).

Ultimate outputs (box 5) are those pre-ultimate outputs which are inputs to, or elements of, the quality of life (QOL)—as contributed to or enhanced by the specific sub-system.

The linkage marked (b) concerns the input or utilization of the immediate outputs of R. & D. (e.g. innovations, patents, ideas) to relevant social activities (e.g., health care, law enforcement).

For example, consider a sub-system of Criminal Justice: Law Enforcement (LE). Some immediate outputs of R. & D., e.g. innovations in the area of communications, may be utilized by the components of the LE subsystem, in its regular operations. We must, however, distinguish between innovations developed specifically for the LE subsystem and all innovations in the field of communications. In other words, due to the lag times in the technology transfer process, innovations in communications may have been produced in time x, whereas the LE subsystem incorporates or adopts the innovations in time $x+y$. Any causal association would require the consideration of the lagged reactions of the subsystem to the innovation.

The analysis of each subsystem in the R. & D. stage may uncover additional intermediate stages, and subsequently, additional measures.

The association between intermediate and pre-ultimate R. & D. outputs refers to the input to the social subsystem and the output of the same subsystem. Again, considering the LE subsystem, the output of the subsystem may be measured by such indicators as the number of crimes detected or solved, or other indicators of the performance of the subsystem.

A major problem in the process is the definition of the output of the social subsystem. LE output measures are subject to political considera-

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[2] From Progress Report No. 1 to Science Indicators Unit, National Science Foundation, "Exploration of Output Indicators from R. & D. by A. H. Rubenstein and E. Geisler, June 1975.

tions and may undergo a process of distortion, primarily due to their role in the evaluation of the subsystem and members thereof. A suggestion which we may adopt from the "social indicators" movement is the use of multiple indicators to measure the output of the subsystem, particularly if the measures vary in different parts of the country (the latter is true in the LE area).

The last stage in the chain refers to the relationship between the output of particular social subsystems and ultimate measures of quality of life and social and economic welfare. Due to the current state of knowledge (or lack thereof), there are several "missing data links" in prior stages. Therefore, attempts to relate the immediate outputs of R. & D. directly to the ultimate measures of QOL are quite tenuous. There have been numerous attempts to measure the quality of life, mainly in terms of a set of indicators or indexes. However, relating such indicators of ultimate social outputs directly to immediate R. & D. outputs is certainly an oversimplification of the process at the present state of the art, since there is little empirical data to support the connection as yet. It is evident that the tracing of the impact of R. & D. becomes more difficult as it approaches QOL. Each stage contains its own data and inference problems and many intervening processes which are complex and defy precise analysis.

For some agencies, identification of the "social subsystems" indicated in figure 1 is fairly straightforward. For others it is not. The complication arises from a number of sources:

Use of a particular process, product, material, idea, or bit of information from a given agency is often made in an entirely different area than that intended or envisioned by the innovators.

The time lags are very long in commercialization and application of many R. & D. outputs and specific outputs become hard to trace.

The paths followed by particular innovations or R. & D. outputs is far from smooth or straightforward; modification, combination, and substitution are common along the path of the R. & D./Innovation process.

Tracing and score-keeping are complicated by secrecy, difficulty in identification and measurement, and lack of a mandate on the part of most agencies to spend much effort and resources on such tracing; for some of those agencies that have tried, such tracing is often concentrated on the large, visible outputs that have some glamour associated with them, rather than the full mainstream of results of their entire program's efforts (including possible negative ones).

The assignment of "credit" for invention, innovation, or origination of an item that is considered worth reporting is often a matter of some controversy; for successful outcomes, there is no lack of claimants to major or decisive contributions to their success.

The general lack of enthusiasm and techniques for assessing negative outcomes of R. & D. programs, i.e. costs to various social subsectors as a consequence of introduction of new products, processes, materials, or systems or lack of such introduction.

Lack of an agreed-upon method of computing costs and benefits to various subsectors and society as a whole.

Figures 2–5 [3] present some illustrative indicators related to the various stages of the R. & D./I process for several areas of FC/R. & D. —energy, transportation, health care, industrial products and processes. Despite the above difficulties, many attempts have been and are being made to do such measurement. We feel strongly that useful results can be achieved by improved methods of identification, measurement and analysis of the results of Federal civilian-oriented R. & D. (FC/R. & D.). However, in order to accomplish this, serious efforts will have to be made by both the originating agencies and other organizations to monitor and trace the flow of innovations from R. & D. to other "downstream" phases of the overall R. & D./Innovation process. That is, if there is a sincere interest on the part of the Federal executive or legislative branches to determine the benefits from R. & D. on a continuing basis for the purposes of improvement in the process, legislation, and policy-formation, then resources must be provided for the measurement and analysis required. I say this with mixed feelings, because many of the new "evaluation" efforts in Federal programs are running wild and need, in turn, to be evaluated for cost benefits to the society and to the programs which they are supposed to be evaluating. Much of the effort being devoted to such "evaluation" is currently distracting from the prime mission of the agencies or programs being evaluated. I think some of this will sort itself out as evaluation methods are improved, as specalists are trained to do both the conceptual and mechanical aspects of evaluation, and as agency and program managers begin to view evaluation as an integral part of performing their mission, rather than an intrusion on their prerogatives and normal operations. The entire U.S. R. & D. establishment has been relatively free of pressure for output measurement and evaluation until recently, and it will take some time for the people in the R. & D./I process to get used to the idea that their output must and can be evaluated on a continuing basis and to tool up to contribute to it, so that it is not "done to them" entirely by outsiders. The idea of evaluating returns from R. & D. is not foreign to industrial R. & D., where efforts have been made to do so for decades, at the individual company level. The fact that few of these efforts have been fully successful or convincing to top management or have become standard and widespread is less a reflection of the motivation of R. & D. people than the lack of capability and techniques to do the job and lack of a consensus among their non-R. & D. colleagues on how "credit" and blame should be apportioned.

Measurement of effectiveness of R. & D., then, is not merely a matter of technique, even in the private sector which is very conscious of cost/benefit type of thinking. It involves agreement on both the need for such evaluation and the methods of approach which will be both accurate and fair to the parties concerned. And it needs adequate time and resources for the measurement process itself.

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[3] From the series of reports to NSF on "Exploration of Science Indicators" by A. H. Rubenstein and Eliezer Geisler, op. cit.

3. Extent of Application or Utilization of Results of FC/R. & D. Programs

Some results are easy to identify. One can, for example, see nuclear powerplants and communication satellites (or at least know that they are up there). New transportation equipment and systems, law enforcement equipment, educational materials (e.g. computer-related), and other "things," especially big and expensive ones are easy to see and, perhaps, evaluate in a superficial way. Most results of FC/R. & D. are not very big, visible, or easy to evaluate. Much of the output of FC/R. & D. programs, whether directly from federal laboratories or from the laboratories of their contractors and licensees are in the form of "in process" innovations, ideas, information, conceptual approaches, techniques, potentially useful and economical materials and methods of fabrication or services. For this reason, we have been attempting to probe into an area that we call "embedded technology," which is not at all obvious and visible, even to the users. Many of the findings and innovative outputs of FC/R. & D. are tightly embedded in products, processes, materials, and systems which are in wide and increasing use throughout society. Some categories are:

Metal forming techniques.

Coatings, including paints.

Design of equipment (e.g. the spinoff of numerically controlled machine tool techniques from Air Force contracts in the 1950's).

Computer programs, technology, designs, and software.

New and improved materials and methods of making them.

New and improved components.

Management and operations methods for a wide spectrum of systems.

The difficulty with this embedded technology, as with some of the direct technology discussed above, is that it is not clearly discernible as a direct, integral unit contribution from a particular Federal program or agency. New hardening tehniques for materials, for example, are currently incorporated in thousands of products and the user and even the makers of these products do not know of or are not interested in the contribution made to developing, testing, and improving these techniques by Federal programs. Any measurement system established for such "nonobvious" R. & D. outputs would have to be arbitrary and would have to probe deeply in a wide area of the public and private sectors. This does not mean that such an effort is not feasible or desirable. But it does mean that, if a serious effort is made to measure the results of R. & D. on a continuing basis, this important part of the output must be included and resources provided for the difficult job of detection and measurement.

When we think about the adoption, application, or utilization of results from the R. & D./I process, we are sometimes tempted to think of them as single acts or single decisions, made at a point in time in a monolithic form. This is far from the real situation. One of the reasons for the low level of application of the results of R. & D. is that a great

many considerations, decisions, and actions are involved in the typical commercialization or other utilization of even a single innovation—e.g. a new product or process, other than minor improvements.

In a recent study of the use of the Federal procurement process as a source of influence on technological innovation,[4] we identified a large number of actions and decisions, each influenced by a number of economic and other considerations, which were potentially part of the utilization or application stage. They are (not in order of importance or sequence):

Decision to bid on a development contract.
Decision on whether to set up a special organization—e.g. a project group.
Whom to assign.
How much resources to allocate.
Key man assignment or less capable person.
Full entrepeneurial responsibility to project leader or less.
One shot versus follow-on.
Go into it on a full scale or not.
Make or buy components, materials, services, facilities, products, equipment.
New facilities or equipment.
Merger or acquisition to obtain technical, production, or marketing capability.
Tooling—new, extent, quality.
Market research—degree of effort and commitment.
Set up new distribution system or change existing one.
Reps, direct selling, other forms of distribution set up on a project basis.
Initiate or accelerate R. & D.
Hire specialists.
Bid high or low—buy into it for sake of follow-on or building credibility or reputation in the field.
Decision to innovate beyond the specific order.
Critical path behaviors or events: tooling, letting subcontracts.
Entry into a new field or just moving slightly to one side.
Set up separate government product division or group.
Optimize profit on a particular order.
Separate/integrated organizational form.
Project/functional setup of R. & D. and related innovation activities.
Assignment of personnel.
Level in the organization (how important is the project).
Investment level and allocation to different phases of the R. & D./I process.
Source of funds—cash flow, reserves, go to bank, long term debt.
Search or devoting selective attention to opportunities.
Pursuit of an RFP or solicitation a bit afield from regular lines of business.
Investment of time, manpower, money, executive attention in search/bid activities.

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[4] From Albert H. Rubenstein and Michael Radnor. "A Model of the Responses of Industrial Firms to Federal Procurement Incentives: A Report to the Experimental Technology Incentives Program (ETIP) of the National Bureau of Standards, U.S. Department of Commerce," Northwestern University, June 1975.

Firm's awareness of RFP. Extent and level in organization.

Decision to set up program in organization on major footing.

Decision to engage in R. & D. beyond RFP delivery needs.

Decision to tool et cetera for longer run production.

Perceived opportunities and costs of specific procurement and commercial follow up.

In view of this large set of actions and decisions involved in the application/utilization phases of the R. & D./Innovation process, it is difficult to make a clear statement about the extent to which the results of FC/R. & D. are actually applied. If we are only concerned about the final, ultimate application or utilization, without considering the reasons why most (probably more than 9 out of 10) innovations fail to be used in the end, we can say that very few R. & D. results, in any sector, reach full application or utilization, other than the large number of routine minor improvements in products and production processes. Our estimates in the industry sector are that fewer than one major new product per year per industrial sector is about the order of magnitude of success of industrial R. & D. (e.g. a totally new drug, fiber, machine, or production process). Since the objectives of many of the projects and programs in the Federal civilian-oriented R. & D. programs are, in a sense, revolutionary, we cannot expect a much greater or even as great a success rate as the industrial sector achieves for its own sponsored R. & D. For the main bulk of applications and utilizations of FC/R. & D. we shall have to look at the less spectacular, continuous improvements that I have called, at the beginning of this paper, "embedded technology" and whose measurement is, at the moment, beyond the state of the art.

Results of recent studies [5] of the application/utilization of Federal R. & D. results further suggest the difficulty of trying to trace the reasons for the large number of failures to fully commercialize or implement the results of Federal R. & D. Many of these factors are well beyond the control of the Federal Government (e.g. through direct or even indirect incentives or removal of barriers) and many of them are beyond the control of the industrial firms or local governmental units who are attempting to make the application/utilization. Some of the most significant factors from three recent studies at Northwestern are indicated in figure 6.

Despite the large number of factors in figure 6 which are beyond the control of the source or user, there are some which are subject to change by the Federal Government. Some of them relate to the frequency and quality of information and contact provided by the sources of the innovations—the Federal laboratories and their contractors. More will be said about this in the last section of this paper.

4. Some Specific Issues Relevant to the Improved Effectiveness of Federal Civilian-Oriented R. & D.

If the output and effectiveness of FC/R. & D. are to be significantly improved, certain issues have to be faced and resolved over the next few years. Some of these are issues that have already been considered (in some cases repeatedly) by a number of Federal agencies, academic

[5] Our research group at Northwestern has recently done a number of studies of the application/utilization of the results of Federal R. & D.—some of them civilian spinoffs from military programs and some of them from civilian programs—e.g. NASA and other agencies.

policy specialists, congressional committees, and others. Few of them have been resolved in a manner that gives clear guidance to improving the R. & D./I process and the output of results to the economy and the society. These issues are:

4.1. How Far Along the Laboratory-to-Market Process Should the Federal Government Be Active in Attempting To Stimulate the R. & D./I Process

Current experimental incentives being tried or proposed in various agencies focus on different phases of the process—from improving the R. & D. itself, to providing test and validation facilities and funds, to stimulating the coordination of technology sources, manufacturers, users and capital sources. Some of these experimental incentives are being used in an exploratory manner and will require legislation or revised regulations to make them routinely available, if they prove effective in the experimental phases. Others can be used by specific agencies and programs immediately and routinely if they prove to be effective. For those in the former category, certain ambiguities exist in our national attitudes. Some of the incentives will involve actions that appear to be "give aways" of Federal property or preferential treatement to particular manufacturers, distributors, or users in order to motivate them to participate. The ambiguities of our feelings and policies in this area can serve as substantial barriers to improving the effectiveness of such incentives. An example is the current uncertainty about the legality or propriety of granting exclusive licenses to government inventions (discussed below in more detail).

4.2. What Role Should the Federal Government Take in Financing the Commercialization and Application of Results From the FC/R. & D. Programs?

This issue involves the familiar questions of the Federal Government's role in providing or encouraging the provision of venture capital for private exploitation of technological innovations. Opinions on this subject range from complete disassociation of the Federal Government from any commercialization aspects to heavy involvement in direct financing. Intermediate roles involve tax concessions, easing of securities regulations, direct subsidies for some earlier phases of the R. & D./I process, provision of information and Federal facilities at low or no cost, and many others.[6]

[6] Several recent studies by our group and a number of foreign collaborators on incentives and barriers in the R&D/Innovation process conclude that the role of current Federal incentives to innovation at the level of the firm and the individual R&D/Innovation project is very slight. This does not mean that it is impossible to influence industrial decision-making on the R&D/I process through government intervention, but that the many incentives and regulations now in existence are not very effective or even visible to industrial managers who are constantly making decisions about the R&D/I process. See, for example: a) "Factors Influencing Innovation Success at the Project Level," A. H. Rubenstein, A. K. Chakrabarti, R. D. O'Keefe, W. E. Souder and H. C. Young, *Research Management*, Vol. 19, No. 3, May 1976, pp. 15–20; b) "Management Perceptions of Government Incentives to Technological Innovation in England, France, West Germany and Japan," A. H. Rubenstein, C. F. Douds, H. Geschka, T. Kawase, J. P. Miller, R. Saint-Paul, and D. Watkins, January, 1976; and c) "Innovation Incentive Programs in Three West European Nations: France, West Germany (F.R.G.) and The United Kingdom (U.K.)." D. Watkins, B. M. Köhler, A. H. Rubenstein, and R. Saint-Paul, May 1976; both of the latter papers are in press in *Technical Innovation, R&D and Incentives,* edited by Donald E. Cunningham, John Craig, and Theodore W. Schlie, Westview Press, Boulder, Colorado.

Underlying this issue are two major questions which can only be resolved ultimately at the national policy level:

How far into the enterpreneurial and commercialization process can and should the Federal Government get involved?

If there is such involvement, should the Federal Government (i.e. the taxpayers) get a "piece of the action," along with the other parties to the innovation process (e.g. the inventors, the entrepreneurs, the venture capitalists)?

These questions do, of course, involve economic considerations. But they also, and perhaps more importantly, involve questions of the role of government in the market system and how far it can and should intervene in that part of it which relates to technological innovation.

The concept of increased "risk-sharing" is widely advocated, and some of the experimental incentive programs are attempting to assess the effects of such risk-sharing (e.g. provision of facilities and funds at various stages of the R. & D./I process) on the ability and willingness of private investors and entrepeneurs to bring innovation projects to fruition. Of course, there is a good deal of risk-sharing already being done by the Federal Government in terms of direct-funded R. & D., tax concessions (e.g. the write-off of R. & D. as an expense rather than an investment), provision of information on a free or less-than-cost basis, etc. The question is how much further and in what ways can or should risk-sharing be increased. The SBIC program, now well into its second decade, has financed a lot of high technology ventures which might not otherwise have been brought to the stage of commercialization. However, not all SBIC portfolio companies have much to do with exploiting technological innovations and there are questions about whether a large number of "good ideas" are not being funded. Some of the incentives being investigated in the experimental programs of NSF and NBS involve risk-reducing more than risk-sharing. They provide (or might provide, if enacted routinely): improved technoeconomic capabilities on behalf of small ventures; technology transfer officers and facilities (e.g. the new EDRA program of technology transfer officers to stimulate and speed up the adoption of ERDA innovations); and use of procurement procedures, regulations, and funds to encourage innovation in materials, equipment and systems purchased by the Federal Government, in the hope that they will eventually spill over into the commercial market.

4.3. How Can We Measure the Costs and Benefits of the FC/R. & D. Programs to the Consumer

Before we can attempt to measure the impact on consumers, we have the nontrivial problem of identifying the consumers of the FC/R. & D. results. If we consider the consumer to be only the "taxpayer" or the "man in the street," we are in trouble, because we are smack up against the ultimate question of how particular innovations or the innovation process as a whole contribute to or detract from his quality of life, general well being, and satisfaction. This is a task that is far too complex to consider in this narrow area of our society called the innovation process. It gets us into a whole myriad of ques-

tions on what the economists call "externalities"—who pays and who benefits. If consumer or citizen A gets less fun out of life because his neighbor B has a new technological toy (vehicle, noise emitter, or weapon), how do we calculate and offset the cost and benefits to each.

One direction of retreat from this difficult problem is to stop short of this attempt at ultimate measures of cost benefits to consumers or citizens as a whole and back up along the R. & D./Innovation continuum of figure 1 until we reach a comfortable and feasible measuring point.

For example, the costs of pollution-reducing equipment to the purchaser and user may be clearly evident, but the benefits to him or his organization may not, even though the general citizenry benefits from less pollution in their environment. Measurement at the level of the purchaser or user is becoming more sophisticated and, in some instances, less polemic and more economically realistic. If he can (1) avoid penalties, work stoppages or loss of business, and (2) even recover materials or energy and improve his production methods as a consequence of the attempt to reduce pollution, this outcome should be offset against the costs of installation and operation of the equipment. Some analysts and users are beginning to think this way and, if careful measurement and analysis are carried out on a continuing basis, we might get, as a spinoff, very good indicators of the contribution of some Federal R. & D. outputs—e.g. pollution measurement methods and equipment.

4.4. The Effects of Federal Patent and Licensing Policy

The special issue of federal patent and licensing policy is raised frequently in any consideration of barriers and incentives to technological innovation. However, the general and oversimplified view that patent rights or exclusive licensing make all the difference or the major difference in whether a particular innovation will be commercialized or utilized is, indeed, a gross oversimplification. In certain industrial sectors, patents are very important. They provide the protection necessary for an entrepeneur or an established firm to make a significant investment in a new product or process with the assurance (not always warranted) that the fruits of his invention (or the rights to someone else's invention which he secured in one way or another) will be honored and that he will be secure in his exploitation thereof. In other sectors, patents are not very much used and do not offer the classical protection which the notion of "patent" implies. In those fields, cost of entry; speed of entry; ability to advertise, market and service a product; proprietary know-how; ongoing R. & D.; and other factors may mean much more than the mere possession of a patent. In still other industries, the filers of patents count on delays in the system to keep their inventions secret for enough time for them to gain a marketing or cost or other advantage.

In view of this mixed situation, it is not clear that manipulations of the patent system as such will make a tremendous impact on the rate of innovation or the adoption and utilization of innovations from FC/R. & D.

We have been involved in a number of studies related to the particular aspect of this broad area that deals with the issue of exclusive

versus nonexclusive licensing, which has become a matter of political and social concern as well as economic and technical concern. Our investigations indicate that the mere granting of exclusive licenses (now a moot qeustion for some federal agencies in view of recent court decisions) does not necessarily determine or strongly influence the rate at which government-funded inventions will be exploited. Some of the other factors which weigh heavily in this area are:

(1) Degree of exclusivity: range from "completely" nonexclusive, i.e., virtually no screening of would-be licensees, through various restrictive conditions for licensing that reduce the potential set of licensees to a smaller number, to one and only one licensee.

(2) License versus waiver: determined by the relationship of the potential licensee with the project or program that yielded the patent.

(3) Size of fees and fee schedules for licenses.

(4) Size and capability of the licensing office: this can range from a part-time person, with primarily clerical functions, as found in some agencies, to a fully-staffed office of several experienced patent and licensing professionals.

(5) Policies and procedures for interaction with potential licensees: this can range from a tight, bureaucratic "we've got it and you want it" approach to a loose, informal relationship, in which the licensor and licensees are joined in the mutual task of attempting to benefit the economy through licensing.

(6) The degree of aggressiveness with which licenses are pursued by the licensor: this can range from a passive, waiting-for-business posture to an intensive and aggressive campaign of marketing licenses (such as is pursued by some companies, universities, not-for-profits and professional licensing firms).

(7) The restrictions with respect to exploitation lag before the license lapses or is revoked.

(8) The restriction with respect to "earnest money" or earnest effort in exploiting the patent.

(9) The reporting and disclosure requirements in connection with the license.

(10) The availability and cost to the licensee of technical assistance and know-how (including access to the inventor).

(11) The degree of follow up by the licensor to see that conditions of the license and the commitments made by the licensee and the licensor are fulfilled.

(12) The behavior of the licensor in actually revoking or modifying the terms of a license as an "incentive" to others as well as the immediate licensee.

(13) Re-negotiation provisions, which may depend on the path of development of the license and unforeseen circumstances.[7]

[7] From "Preliminary Ideas on an Experiment to Test the Effects of Exclusive/Nonexclusive Licensing"; A Report to Denver Research Institute for the NSF/Department of Commerce Study, by Albert H. Rubenstein and Charles W. N. Thompson.

5. Conclusions and Recommendations

The issue of measuring or even qualitatively assessing the effectiveness of Federal Civilian-Oriented R. & D. (FC/R. & D.) is far from a matter of merely collecting existing data and performing some statistical analysis to see if the output justifies the input. There are some severe conceptual, measurement, and value problems that must be addressed before such measurement or assessment can be done effectively.

Conceptually, the problems involve an analysis of the total R. & D./Innovation process, including its involvement with the social subsystems and supersystems which it is intended to serve or which it serves inadvertently. This means that the various stages of outputs described in this paper require careful study and differentiation in terms of what credit (or blame) the R. & D. part of the process deserves for its contribution. Then there is the related issue of accounting for the other important inputs to the social systems, including political as well as economic inputs. This is crucial, since political and administrative decisions on whether and how to stimulate or inhibit the flow of the innovation process from laboratory to user play a decisive role in whether any ultimate results are achieved.

Measurement problems are also severe for a number of reasons. One is that the entities or events which constitute the potentially measureable output of the R. & D./Innovation (R. & D./I) process vary widely in size, form, detectability, directness, and other characteristics. Decision on a unit of measurement is a task that has defied many efforts over the past few decades to assess the outputs of the R. & D./I process. Given that some units can be agreed upon (e.g., number of new products in the intermediate stages or increase in employment at more ultimate stages of the total process) there is the fundamental problem of imputing to a given input in this complex process the proper quantitative share of credit for outputs from the overall process or the various stages in the process. This is particularly important in a process such as R. & D./I, where many inputs are necessary to achieve useful results and none of them is sufficient to achieve them alone.

Finally, the value questions are perhaps as complex and ill structured as the measurement and conceptual problems. To what extent is the society willing to spend federal funds to support and encourage a process which has the potential, in addition to helping society at large, for helping some individuals and organizations to benefit greatly from involvement in it (e.g., the entrepreneurs and the venture capitalists). Is the society willing to have funds earmarked for a particular social mission contribute to outputs in another sector. If the answers to these value questions are affirmative, then the budgeting, planning, programming, management, and incentive structure of our FC/R. & D. programs should be made consistent with these values.

These comments lead to a few specific recommendations which are in an area of joint decision and action by Congress and the Administration:

1. Clearer guidelines should be established and enforced on how far along the R. & D./Innovation continuum (lab to market place) the Federal Government is willing and able to go to encourage and influence the R. & D./I process.

2. If further real involvement in the process is desired on the part of Federal civilian agencies, the legisaltion, regulations, funding, and reward structure should reflect these desires.

3. Instead of an occasional investigation or quick inquiry into the effectiveness of the FC/R. & D. process in producing useful outputs for society, a continuous, systematic audit [8] should be established to provide guidance on how the R. & D./I process is working in various sectors and what changes are needed to make it more effective.

None of the recommendations mentioned above can be easily done with the flick of a wrist or the announcement of intentions. The size and complexity of the system, with all its inherent uncertainty and time lags, requires that a well-funded, competently-staffed effort is needed to specify the exact changes that are needed in regulations, legislation, operating procedures, and innovation climate to increase the effectiveness of FC/R. & D. Clues to many of the factors involved are given in this paper, but their incorporation into a workable pattern will take a lot of hard work over an extended period, if the situation is to be improved significantly. As a result of the many experiments and studies supported by the ETIP program of the National Bureau of Standards and the RDI program of the National Science Foundation, there is much information accumulating on the barriers to improved effectiveness of FC/R. & D. This information needs to be sorted out, integrated, and utilized in improved design of the process.

6. A Brief Note on the Background for This Paper

I would like to indicate the basis for the observations and recommendations contained in this paper and to disclaim any pretense of a comprehensive "state of the art" review of the literature or "hard data" on the subject.

The observations arise from my involvement, over the past 25 years, in research, consulting, and direct experience with the Research and Development/Innovation (R. & D./I) process in a wide variety contexts—publice and private, foreign and domestic, large organization and small, for-profit and not-for-profit. As part of my consulting activities, I have been involved, since the beginning of the SBIC program, as a director of a Small Business Investment Company, many of whose portfolio companies are in areas of high technology.

Our research on the R. & D./I process at Northwestern (and prior to that at M.I.T. and Columbia) has been supported by a wide variety of Federal agencies and we have been closely involved in the "research-on-research" and "science/technology policy" programs of NSF, NASA, DOD, Army Research Office, NBS, Office of Naval Research, and other agencies.

The observations in this paper, then, reflect a far-from-detached view of the Federal R. & D. programs in general, although neither I nor members of our research group—The Program of Research on the Management of Research and Development at Northwestern—have espoused particular policy positions relative to the focus of this paper—The Effectiveness of Federal Civilian-Oriented R. & D. Programs.

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[8] Rubenstein and Geisler, op. cit.

In the past 3–4 years our research group and a number of us as individual consultants have become heavily involved in the several federal programs attempting to develop and test incentives for techological innovation in both the public and private sectors (e.g. ETIP of the National Bureau of Standards and RDI of the National Science Foundation). We have done studies on: Federal incentives to innovation; exclusive licensing; procurement incentives; technology transfer mechanisms; measuring the outputs of R. & D. (Science Indicators); the use of contract mechanisms to stimulate innovation; the application of technology from federal agencies (NASA, DOD, ERDA, DOT, etc.); and many other aspects of the field of incentives and barriers to application of the results of R. & D.

The issue statements and other comments in this paper constitute an attempt to respond to a number of questions about the effectiveness of federal civilian oriented R. & D. and not to state a coherent policy position or to neatly package all we know in a single model of the process.

FIGURE 1

A CONCEPTUAL FRAMEWORK OF THE RELATIONSHIP BETWEEN R&D AND SOCIAL SUB-SYSTEMS

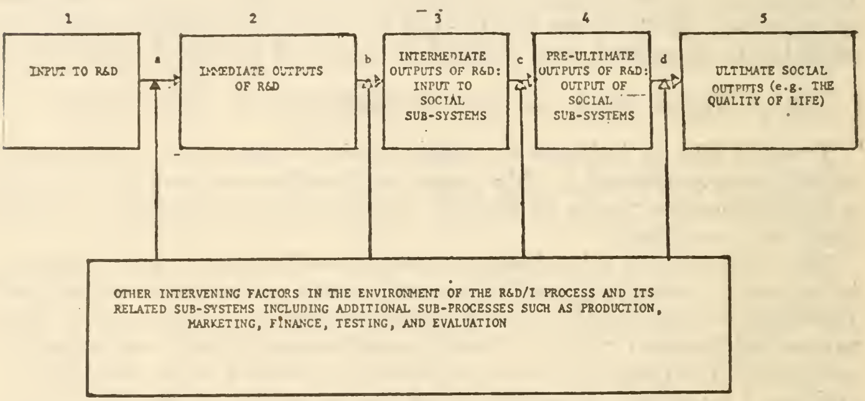

Figure 2

SELECTED INDICATORS FOR THE DISEASE SUBSYSTEM OF THE HEALTH CARE SYSTEM

Intermediate outputs [1]	Preultimate outputs [1]	Ultimate outputs [1]
	Prevention: [2]	Positive outputs:
1. Number of publications in medical research, in medical journals.	1. Distribution of infectious diseases (number of cases/10^6 population).	1. Life expectancy.
		2. Decline of morbidity rate.
2. Number of new drugs adopted for use in Health care.	2. Number of diseases for which inoculation of infants (0 to 2 yr) is done.	3. Eradication of diseases.
		4. Economic benefits from healthy population (e.g., number of working days lost due to sickness causes—reduced).
3. Number of new instruments adopted for use in health care (machines, apparati; devices, etc.).	3. Distribution of diseases treated in out-patient hospital care.	Negative outputs:
	4. Distribution of occupational diseases per population.	1. Population explosion.
4. Number of new diagnostic techniques adopted for use in health care.	Cure: [2]	2. Social and economic:
	1. Death rate by leading causes of death (diseases).	Larger share of older population—nonlabor force.
	2. Death rate by leading causes of death by age groups (diseases).	Economic and social burden of older sector of population.
	3. Morbidity rate by leading cause (diseases).	
	4. Recurring appearances of diseases per population.	

[1] Not necessarily in order of priorities.
[2] Indices compiled from: L. A. Aday and R. Einhorn, "The Utilization of Health Services: Indices and Correlates: A Research Bibliography", DHEW Pub. No. 1 (HSM) 73–3003.

Source: O. W. Anderson and J. Kravitz, "Health Services in the Chicago Area: A Framework for Use of Data," Research Series 26, Center for Health Administration; University of Chicago, 1968.

Figure 3

OUTPUTS OF INDUSTRIAL R&D

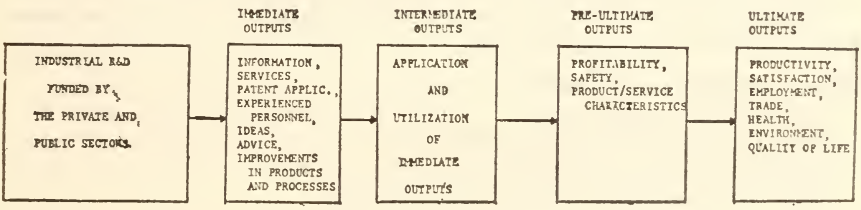

Figure 4.—*Some outputs of energy R. & D.*

The development of criteria for the measurement of the various outputs of energy R. & D. is based on the declared objectives in this field.

Considering, for example, two sub-areas of energy R. & D.—(1) energy conservation, and (2) investigation of the potential for more extensive coal, oil, gas and shale utilization (fossil energy R. & D.)—some output indicators might be:

CONSERVATION

*Immediate output indicators**

Improved economics of electric power transmission.
Improved reliability of transmission.
Improved efficiency of transmission.
Increased storage capability for electric power.
Decreased fuel consumption of automotive engines.

Intermediate output indicators

Safety.
Contamination and health.
Air and water pollution.
Improved energy input to industrial production.

Pre-ultimate output indicators

Conservation R. & D. may lead to:
Increased opportunity for industrial expansion. Leading to:
Increased and diversified industrial production.
Replacement of traditional vehicle systems by those that operate on stored energy or another system.

Ultimate output indicators

Increased in employment.
Increased satisfaction in population.
Increased quality of life.
Balance of payment and balance of trade.

FOSSIL ENERGY

*Immediate output indicators**

Reduced cost of drilling.
Improved detection power.
Reduced production costs.
Increased production of pollution free fuels.
Production of knowledge, methods and technology for coal liquefication and gasification.

Intermediate outputs

Utilization of immediate outputs by industry, utility companies and other social sub-systems (e.g., transportation).

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*Immediate in the sense that they represent new knowledge of the possibility and feasibility of doing these things. This listing represents only a "first cut" at the problem. Much work must be done to further identify and operationalize measures at all levels.

Pre-ultimate output indicators

Production and marketing of vehicles fueled by gas or oil from oil-shale/coal.

Production and marketing of industrial product at lower costs and increased variety.

*Ultimate output indicators**

Decrease in the national dependency on foreign energy sources.
Improved environmental conditions.
Balance of payments.
Increased political influence on international scene.
Increased employment in energy industry and related areas.
Decrease in national fossil fuel reserves (a negative indicator).

FIGURE 5.—*Some outputs of transportation R. & D.*

Immediate Output indicators

Cost reduction.
Routing improvements.
Safety improvements.
Decrease in loss of and damage to goods transported.
Time saved.
Improved energy usage.

Pre-ultimate output indicators

Reduced costs of industrial products at the factory (due to lower transportation costs of raw material and lower manpower costs).

Reduced costs of industrial products (finished goods at end of producer-consumer chain).

Ultimate output indicators

Comfort, convenience and satisfaction of passengers and population.
Decline in air and water pollution.
Economic growth (due to movement of goods and passengers in larger volumes, with less spoilage, more safety and in less time).

FIGURE 6.—*Factors affecting the application/utilization of Federal R. & D. outputs*

(A) *Innovations from NASA—Performed or—Supported R. & D.*,[9] where the organizations attempting to apply or utilize the technology were industrial firms:

*See footnote in Figure 4.

[9] From Alok Kumar Chakrabarti. "The Effects of Techno-Economic and Organizational Factors on the Adoption of RASA-Innovations by Commercial Firms in the U.S.," Northwestern University, Evanston, Illinois. June 1972. A Ph. D. Dissertation. See also A. K. Chakrabarti and Albert H. Rubenstein, "Inter-Organizational Transfer of Technology, *IEEE Transactions on Engineering Management*, February 1976, vol. EN-23.

	Significant for—		
	Product innovations only	Process innovations only	Both
1. Degree of general connection of the technology to the firm's existing operations.			X
2. Specificity of relationship between the technology and some existing and recognized problem.			X
3. Degree of urgency of the problem to which the technology was related			X
4. Availability of personnel to implement the technology			X
5. Difficulty of obtaining financial resources necessary for implementation			X
6. Degree of top management's support for the technology	X		
7. Conflict resolution methods			X
8. Organizational climate factors			X
9. Quality of information received from the source of the technology		X	
10. Maturity of the technology		X	

(B) *Innovations from DOD Programs*,[10] where the organizations attempting to apply or utilize the technology were state and local governmental agencies:

Information availability to the user organization.

Frequency and quality of interaction between the user and the source (e.g. DOD) scientists and engineers.

Perceived relative advantage of the new technology or innovation over current methods, equipment or systems.

Availability of financial resources and technical personnel to implement or adapt the technology.

Top management support for technological change.

The existence of a product champion in the user agency.

User involvement in source decisions about the technology.

Source involvement in potential user implementation difficulties.

(C) *Innovations from Various Federal Agencies*,[11] where the organizations attempting application/utilization were state and local agencies:

1. Clients in state and local agencies are not as naive on matters of technological innovation as some observers suggest. They analyze the possible benefits and uses of prospective technologies in the very first stage of adoption.
2. Organizational climate and administrative support for technical change has a strong influence upon the adoption of federal technologies.
3. Agencies which are successful in adopting federal technologies make a concerted effort to determine how prospective federal technologies relate to an actual problem they have as well as how those technologies provide an advantage over their existing technologies.
4. Few state and local agencies have any means to thoroughly analyze designs or to pilot study prospective federal technologies. This reality stresses the need for federal agencies to produce essentially turnkey technologies which can be implemented without further user investigation.

[10] From William Allen Hetzner, "An Analysis of Factors Influencing the Transfer of Technology from DOD Laboratories to State and Local Agencies," Northwestern University, Evanston, Illinois, 1973. A Ph. D. Dissertation.

[11] From Allen D. Jedlicka, Albert H. Rubenstein and William A. Hetzner, "Factors Affecting the Transfer of Technology from Federal Agencies to State and Local Agencies," *Proceedings of AID Conference*, April 1975. This was an exploratory pilot study with a very small data base.

THE RELATIONSHIP BETWEEN FEDERAL, STATE AND LOCAL GOVERNMENT SUPPORT FOR RESEARCH AND DEVELOPMENT

By WILLIAM D. CAREY*

INTRODUCTION

As this is written, towards the close of 1975, research and development still touch only the fringes of Federal-State-local relationships in the United States. While the infrastructure of intergovernmental relations has continued to deepen and diversify and to be the subject of lively policy debate, there has emerged no intergovernmental strategy based upon cooperative action for anticipating and resolving problems through R. & D. True, there is a trickling-down of R. & D. funds through the well-known "marble cake" of federalism—though no one can confidently measure or describe it—but this either represents longstanding practices (e.g., the Agricultural Experimentation Stations research program) or is *ad hoc* and opportunistic. R. & D. have yet to come of age as a significant currency in intergovernmental relations, and they are unlikely to do so in the foreseeable future.

The explanation is both straightforward and complex. R. & D. funding is a well-settled Federal monopoly as the public sector goes in the United States. Except for a few erratic and short-lived programs (Model Cities, UMTA "demonstrations") the notion of jurisdictional joint R. & D. funding has not been attempted. The maze of "categories" of Federal assistance cover a great deal of ground, but there are no categorical programs for R. & D. The one Federal attempt to field a program for technology transfer—the State Technical Assistance Program—became politicized and was abruptly terminated by the Congress in 1969.

While it has never occurred to Federal policy-makers to propose a systematic intergovernmental delivery program for R. & D. results, neither have the State and local governments seriously sought one. R. & D. has not been eyed as a panacea by these levels of government, and there have been no incentives and rewards to change their minds. R. & D. are well-understood by States and cities to be costly and speculative areas of expenditure, with distant payoffs at best, and only when these units of government have faced such baffling policy problems as environmental control and energy management have they begun to move in the direction of independent research and development funded from their own budgets. On the whole, they have been satisfied to leave large-scale R. & D. to "the Feds."

*This is one of a series of papers commissioned by the Congressional Research Service on behalf of the Joint Economic Committee of the Congress. It reflects the personal views of its author, and should be read as an individual "think piece." Although the writer is the chief operating officer of the American Association for the Advancement of Science, the paper has not been reviewed by the Board of Directors, and the author bears full personal responsibility for the statements and opinions which are expressed.

What emerges is a situation in which all of the major cost and management problems now encountered by the States and cities—crime, transportation, welfare, housing, and education—are blanketed by Federal R. & D., with only small and marginal capacity on the part of those governmental units closest to the problems and the tax burdens. To complicate matters even more, the States and localities have had almost no practical experience in contracting for and evaluating R. & D., and it is doubtful that they could get off to a fast and effective start even if they had to. Before they climb on the R. & D. carousel, it would be well to make assistance available to them regarding the best practices of Federal and industrial research managers in project definition, evaluation of performance, and cost control.

The Facts of Life

State and local governments comprise a "Fourth World" in the politics of R. & D. The other three worlds are the Federal Government, industry, and the university/nonprofit sector. The three primary elements have constituted the "system" since R. & D. became a big business in the United States. The arrangements were convenient and effective: The Federal Government determined the objectives and provided the financial stimulus; the industry sector performed most of the developmental work, sharing the "applied" research with Federal R. & D. centers; and the universities (including State-supported institutions) did most of the fundamental research. State and local governments as such were excluded since they had nothing to offer except a vocal interest in the siting of R. & D. facilities and the geographic distribution of research grants and contracts. In a sense, of course, the latter served as a kind of proxy for an "intergovernmental R. & D." strategy, in that it had the side effect of concentrating valuable R. & D. assets in favored states and sub-state regions, notably Massachusetts and California. While the economies of these states derived substantial benefits from these allocation decisions, it would be very hard to make out a case that substantial benefits accrued to the enlightenment or the effectiveness of the host governments.

The State and local governments, having come late to the R. & D. feast, are still a minor factor in the demand-supply market. Their requirements do not yet make a difference in the economics of the R. & D. industry, and certainly have not figured in influencing the intensity or expectations of the techno-scientific enterprise. That enterprise still has its attention riveted on the Federal Government, and State-local requirements do not constitute even a secondary market of interest. It is normal for R. & D. institutions to pounce on the Federal budget before the ink dries to find out what is in it, but all the State budgets together send out no more than a feeble signal.

Not only is a financial partnership absent in intergovernmental R. & D. relationships, but neither can one find a systematic *process* of policy or administrative cooperation. There are isolated patterns of cooperation in shaping common needs for R. & D. in, for example, the fields of highway research and environmental protection. ERDA will very probably be the next Federal agency to have formal consultative links with State and local governments. But there is no policy pressure on the agencies from the Executive Offices to formulate domestic

R. & D. programs and budgets in concert with the State and local governments, nor a crosscutting R. & D. budget analysis of the intergovernmental R. & D. It can also be said that there has been no policy pressure from the Congress, other than to try to salvage the National Science Foundation's modest intergovernmental science program from policy neglect. In fact, the Mansfield Amendment has served to chill the policy climate and discourage agencies from diversifying their missions to deal with State and local needs.

Clearing the Air

This paper will not argue that State and local governments should be flooded with Federal R. & D. funds and programs. For the most part, the answers to the dilemmas of these governmental units are not to be found in scientific research as much as in the applications of R. & D. results already on the shelf, in changes in institutional practices and incentives, and in selected developmental technology to improve basic public service delivery with a higher yield in productivity: fire control and detection equipment, low-pollution waste treatment technology, and multijurisdictional land use and health care facilities systems—needs which come within the definition of public technology. Beyond this, State and local governments have a growing need for scientific and technical *capacity*—the in-house know-how to cope with problems of decision making which involve close judgments in areas of scientific and technical dispute or uncerainty. These are decision-making dilemmas which arise in investment planning, energy facility siting, land use controls, coastal zone management, regulatory procedures for health and safety, and a wide spectrum of standards-setting, enforcement, and judicial routines. If there is one extremely strong opportunity for a new intergovernmental initiative in science and technology, it lies precisely here: the urgent need to help State and local governments to acquire the *informed capacity* for legislating and rule-making in complex fields of public policy where scientific and technical questions abound. A Federal transfer of money is only a part of what is required; the generous transfer of expert personnel, through the Intergovernmental Cooperation Act process, could do even more to augment the capacity of the State and local governments for coping.

Leveraging the massive Federal R. & D. expenditure to gain a greater yield to State and local governments is a strategy more likely to pay off than beginning as well-meant but open-ended categorical program to dump R. & D. dollars on those jurisdictions. In order to manage a new categorical program, the State and local governments would have to set up new machinery and incur substantial overhead. If the program called for matching funds, the States and cities would be hard-pressed to provide them, and probably disinclined to do so beyond a token participation. On the other hand, these jurisdictions could participate at low cost and zero risk in the early and middle stages of Federal R. & D. program formulation and project design, with expectations of results which are keyed to their adoption and benefit. If anything has been learned about "technology transfer," it is that the user must get in on the act at the start of the R. & D., help to define the questions to be investigated, formulate both the end product (or process) characteristics and the constraints (such as final user

costs), and participate in evaluation and testing. If these conditions are met, there is a fighting chance that there will be a transfer of technology. The problem is that they seldom are met, and the transfer does not come off. This goes far towards explaining why Federal R. & D. results are stranded at the junctions of State and local government, notwithstanding a proliferation of "technology transfer" offices in Federal agencies. But if the "top down" philosophy of Federal R. & D. decision-making could be changed to a shared process, the State and local governments would be in a favored position to leverage Federal investment in R. & D. in those problem sectors which lie close to the nerve. This kind of intergovernmental cooperation in R. & D., if coupled with an effort in capacity-building of the kind discussed earlier, could make a material difference at little if any incremental cost.

The absence of a large state and local outlay for R. & D. is not a *prima facie* indication of governmental lag or ineptitude, though it is sometimes mistaken for it. R. & D. need not be gaudy to be sufficient, nor is a frantic effort in R. & D. necessarily a sign that all is well with public administration. The State governments have willingly, if prudently, supported R. & D. in their own institutions when state interests required it: for soil conservation, forest management, agriculture, public health, and economic development. Where R. & D. has been slower to arrive in State government affairs has been in the relatively recent problem mix involving urban concentrations, population movements, and the impacts of technological shock. In a real sense, however, these priorities approached on cats' feet and were quickly preempted by Federal interventions. That R. & D. has done little to solve them has not escaped the notice of State and local governments, though perhaps it is not so much the failures of R. & D. as it is the resistance of public and private interests to adapt. On the whole, the State and local governments have avoided the ploy of substituting R. & D. for action, and they have not tried to dazzle the voters with scientific dog-and-pony shows. Whether State and local governments have spent "enough" on R. & D. is unanswerable as an abstraction. Relative to what? Relative to the gaps in knowledge, or to the rate of escalation in debt and tax burden, or to the unknowns which the next decade will bring, a judgmental answer would be that they are under-investing in R. & D. But relative to their budget margins, or to the heavier claims of meeting current workloads, or to their present capacity for R. & D. planning and management, or to their arrangements for problem-solving on a substate regional basis, the answer could as readily be that R. & D. outlays are a reasonable reflection of reality, at least until such time as an operative intergovernmental relations breakthrough can be negotiated.

The Federal Policy Role

Federal policy leadership to integrate State and local governments into the R. & D. enterprise has been centered in the National Science Foundation, where it has lived dangerously and survived by ingenuity. With modest resources but a lively imagination and an inclination towards risk, the Office of Intergovernmental Science Programs has fielded a striking menu of policy research studies, prototype State/local science and technology centers, and Federal-State working conferences on requirements/supply problems. In many instances, NSF

has provided the front-end capital to get State and city governments up to traveling speed which has enabled governors and legislatures to assess scientific and technical information for policy making purposes. In addition, NSF has tried to assemble an aggregated State-local market demand for science and technology by assisting in the creation of regional urban networks for defining common needs and exchanging experiences. Considering the financial and policy constraints within which NSF has been obliged to work, as well as the relatively obscure status of NSF in the Federal power lineup, the results are impressive. There now exists a framework of State and local know-how which can be kept in place and scaled up to carry a stronger burden of intergovernmental cooperation, should things turn out that way. But not even the NSF has been successful in following up its initiatives with a breakthrough in intergovernmental relations policy. Its work with State and local governments has been viewed more as a pattern of typically altruistic gestures than as a serious new start in intergovernmental affairs. In political terms, NSF has not built a State-local constituency with sufficient conviction and self-interest to force the federal government towards a reorientation of its R. & D. arrangements, and NSF itself is in no position to play the role of advocate even if it had an inclination to try. Its priorities lie elsewhere, in advancing the progress of science and higher education, and in keeping clean hands as it attempts to administer the RANN program. Its interest in intergovernmental R. & D. is a barely marginal one, though signs of growing policy support are beginning to be seen. In this perspective, what has been accomplished has to be rated as remarkable.

Limitations in the States

If there are foul-ups in the Federal system which thwart State and local involvement in R. & D. programs, there are also imperfections within the State systems. The roles of State universities come to mind. Since the public university is a creature of the State, a presumption exists that these institutions should be valuable sources of scientific and technical service to State and city governments. The evidence is that things do not work out that way. The universities have missions of their own to see to. Their R. & D. capabilities are largely financed by the Federal Government. Top-flight university researchers are typically supported by the Federal grants which they assiduously seek. Few incentives and rewards are offered by State governments which can compete with the Federal varieties. The needs of governments are likely to be for quick answers to today's problems, whereas university R. & D. is characteristically long-range and fundamental. *Ad hoc* services to states and cities tend to disrupt R. & D. routines and academic scheduling, and are seen as diversions. For all these reasons, university R. & D. capabilities are seldom focused on state and local government service even though, in some states, legislation provides that salary advances and promotions must be based in part upon evidence of service to the government. In practice, this requirement is inconsistently observed. The economic faculty is more likely to be found providing consulting help than is the physics or chemistry department, although the gradual emergence of interdisciplinary university centers for environmental or energy studies suggests an affinity to governmental concerns which may turn out to

be productive. A few states, like Illinois, have bypassed the universities by creating autonomous institutes of the "think tank" variety in order to create new and better incentives for responsive R. & D.

In general, the prognosis is that State universities will declare themselves in favor of public service but, in practice, will preserve their independence to decide each case on its merits. It is difficult to dispute the university's right to make a choice as to the propriety and priority of the summons to service, and to decide what is the best use of its skills. Where the State defines a particular service which fits in with the stream of the university's concerns and interests, there is a probability that something can be arranged. But if the request is seen as a distraction, a setback to important work in progess, or an interference in the ordered regime of the university, the institution is likely to resist. One remedy is for the State government to negotiate with enough lead time to enable university administrators to work out manpower and teaching adjustments; it is the firebell-ringing approach which causes much of the trouble. But lead times are not always available to State or local officials, and the torture involved in doing business with the universities is a strong deterrent to a productive relationship. To a frustrated governor, the knowledge that the university's R. & D. talent is knee-deep in Federal grants, contracts, and proposal-writing can be infuriating, and he is likely to look upon the university as more of a Federal than a State institution. While direct Federal relationships with State institutions and their research facilities are perhaps not the major problem of intergovernmental relations in R. & D. they are nevertheless a complicating factor from the standpoint of the States. The question never is asked, at the Federal level, whether the award of research support will preempt the State government from levying requirements for service upon the State's university. Nor, so far as is known for that matter, has a State chancellor of higher education ever interfered in the bilateral relationship between the State institutions and the Federal Government. Until that happens, or until Federal research funds become scarcer, the university/State government relationship will remain a troubled one.

State R. & D. Expenditure Profile

The most recent data on State government R. & D. expenditures are found in National State Funding Report 75–303, and cover fiscal years 1972 and 1973. Because of the effects of the economic recession on State budgets, it is not likely that State R. & D. efforts have increased since 1973, and may even have declined. One can take either a cheerful or a gloomy view of the meanings of the state numbers. The cheerful view is to note a nearly fourfold increase from 1964 to 1973 in current dollars. The gloomy view points to the fact that the absolute totals are still very small, the fact that the States put up only 48 percent of the R. & D. expenditures from their own funds, and the fact that two States— New York and California—made up 36 percent of all States' expenditures for R. & D.

NSF reports that State government agencies spent $264 million in R. & D. in 1973, or 0.9 percent of national R. & D. expeditures. To reach this level, State expenditures for R. & D. doubled from 1967 to 1973, and Federal funds transferred to the States account for 50 percent of

the expenditures credited to the States; the real effort measure thus is reduced to $130 million, in round numbers, if one is trying to determine the degree of State governments, direct, R. & D. investment policy. On the other hand, the split suggests that if a Federal-State relationship did not exist in R. & D., modest though it may be, State governments would look considerably worse than they do. This optimistic view fades rapidly, however, when the $130 million of Federal R. & D. assistance is compared with a $45 billion total of all Federal aid to State and local governments in 1973: Three-tenths of one percent of Federal aid goes for R. & D., and as the total of Federal aid has risen since 1973 to an estimated $55 billion in 1976, while State R. & D. expenditures have grown little if at all, the fraction of relative Federal R. & D. assistance would appear to be nearly microscopic.

State variations in the level and intensity of R. & D. expenditures are striking. As the NSF analysis points out, 15 states accounted for about three-fourths of total state R. & D. expenditures (including Federal R. & D. assistance). The other 35 States spent the remaining 25 percent of the R. & D. funds. The distortion is worsened by the fact, already alluded to, that two States accounted for 36 percent of total R. & D. expenditures. NSF also points out that 13 of the top 15 States in R. & D. spending ranked among the highest States in population and personal income. This clearly suggests that taxing capacity, combined with the concentration of problems which grow out of impacted urban areas, is a policy factor in determining the distribution of Federal/State R. & D. dollars. As for where the R. & D. dollars were applied, NSF's tabulation indicates the following for 1973:

	Millions
Biological sciences	$83, 280
Clinical medical sciences	38, 123
Psychology	18, 655
Physical sciences	7, 065
Environmental sciences	13, 851
Mathematics	1, 860
Engineering	30, 456
Social sciences	67, 145
Other	3, 341
Total	263, 778

In passing, it is significant that the National Science Foundation places a gentle *caveat* on the reliability of these data, observing that they are limited by definitional problems at the state level, while the trend indicators of growth could be hampered by prior underreporting. Matters are not helped by NSF's neglect of surveys of State and local effort. Such surveys should be made at least at 3-year intervals.

When data for 1974 become available, they are likely to show a hump in State government R. & D. spending, attributable to the energy crisis. The Energy Staff of the National Governors Conference, supported by NSF and other agencies, operates as a clearinghouse for the State governments and maintains a computer bank of information on all State programs and policies related to energy matters. According to NGC printouts, the States funded $55 million of energy R. & D. in 1974, and even this total may be understated for reasons of misclassification. Significantly, this total represents the State's *own* funding, and

not federal assistance for R. & D. The breakdown is interesting on several counts. One-half of the outlays went for R. & D. on coal, with Kentucky putting up $16 million and Illinois $8 million. The next largest R. & D. target was plant siting and nuclear power, at $8.1 million (half of the total coming from Maryland), closely followed by energy-related transportation research ($7.6 million) almost all of which was funded by the State of New York. Taking the total amount ($55 million) reported as state funding for energy R. & D. in 1974, one finds once again that 4 States account for 70 percent of the outlays (Kentucky, New York, Illinois and Maryland).

The overall profile of state government R. & D. expenditure is, on balance, one of subscritical effort relative to comparative benchmarks (total State government expenditures, steeply rising costs of government, total federal aid to states and cities, and gross national expenditures for R. & D.). It also reflects a skewed distribution of investment effort in favor of a minority of the State governments which enjoy relatively strong fiscal capacity, inferring that States with developmental needs are not participating significantly in R. & D. The richer States benefit from R. & D., while the less-favored States lag behind. If federal R. & D. policy were to condition financial assistance on a requirement for multistate diffusion of results and applications (R. & D. sharing) this gap might be reduced, and the opportunities for more rapid emulation enhanced. Here a presumption is made that lateral transfer of innovation (state-to-state) has greater potential than vertical transfer (Federal-to-State). Pilot experiments, if carried out with NSF support, could test the validity of the presumption.

The prospects for much growth in State government expenditures for R. & D. are not good in the near term, largely because of constraints on both Federal and State budgets. The Federal impulse to combine a major tax reduction with an equivalent expenditure cutback puts all discretionary spending at risk, including general-purpose R. & D. At the state level, according to the Joint Economic Committee, 20 States will enact tax increases in 1975 while 22 states will make expenditure reductions amounting to nearly $2 billion. Broadly speaking, R. & D. is attractive to governments during periods of economic growth and budget surpluses, while conversely R. & D. cutbacks are a painless target for economizing. The sensitivity of State R. & D. spending to the barometer of federal assistance is obviously high when one-half of total State R. & D. outlays come from Federal agencies. Moreover, the financial squeeze affects not only the performance of R. & D. but equally the availability of funds for applying R. & D. results, so that R. & D. gets it coming and going. Stranded applications of R. & D. tend to obsolesce on the shelf, suggesting strongly that the prior expenditure on R. & D. is likely to produce no payoff.

Local Government R. & D. Spending

The last time that local governments were surveyed by NSF for R. & D. expenditures was for 1969, and one is obliged to rely on informed guesses as to what has been happening since. In any case, the picture is not overwhelming. National Science Foundation found that in 1969 local governments spent $40 million on R. & D., roughly twice as much as in 1966. Half of the money came from Federal agencies, and 13 percent from State governments and other sources. The effort

level of local governments therefore dwindles rapidly from an apparent $40 million to a more realistic $15 million in 1960. Even if the aggregate estimates of $40 million are taken at face value, R. & D. accounts for less than one-tenth of one percent of total local government expenditures, as the National Science Foundation survey pointed out. If, lacking any actual data for the years since 1969, we assume another doubling of aggregate R. & D. spending by local governments, the ratio comes out about the same since total local government expenditures have risen considerably faster.

As was the case with State governments, the distribution of R. & D. spending at the local government level is anything but balanced. In the 1969 National Science Foundation study, out of 147 reporting jurisdictions, 10 accounted for 53 percent of total R. & D. outlays while 5 of those made up 38 percent of the total. The highest spenders were New York City, Boston, Philadelphia, Los Angeles County, Cook County, Los Angeles City, Baltimore, Chicago, the Bexar County (Texas) Hospital District, and the Marion County (Indiana) Health and Hospital District. Beyond these 10 local governments, the flow of R. & D. funds was very thinly spread. In attempting to interpret such indicators, one soon reaches the conclusion that R. & D. activity in local governments reflects variations in grantsmanship skills and in perceptions of local officials towards the relevancy, or lack of it, of R. & D. in problem solving. However, that may not be the whole story. Other factors probably include an aversion of Federal R. & D. agencies to making grants of research funds to local governments which have no track record in the R. & D. business, together with apprehensions about accountability for fund control and concern as well as to rapid turnover of local elected governments. Finally, Federal agencies have had a residual sensitivity to bypassing State governments to deal directly with local units which may be at political odds with State legislatures. While these various prejudices are now out of date, they were among the barriers to Federal-local R. & D. relationships.

If more recent survey data were available, they would probably show that Federal R. & D. funds have accelerated relative to local governments since the 1969 survey. LEAA, EPA, and ERDA are the most likely sources of these increases, together with NSF's targeted funding of city consortiums and scientific advisers. On the other hand, the fiscal crunch which has overtaken many local governments has undoubtedly led to curtailments of local R. & D. investment. At least one case in point involves New York City, which wiped out its longstanding multimillion dollar health research program as an economy move. In its 1969 report, National Science Foundation cited various "negative influences" affecting the level of R. & D. activity by local governments, including inadequate financial resources, lack of qualified scientific personnel, legal restrictions, resistance of departmental personnel, and lack of support from elected officials. Some of these built-in barriers have become more permeable since 1969, however, largely through patient and low-key work by the National Science Foundation in creating capacity in local governments. Having said that, the fact remains that American local government is still underdeveloped country for R. & D. and at least a decade of intensive work would be needed to achieve a substantial difference in local government effort and capacity.

Putting R. & D. To Work

Despite the shortcomings in R. & D. effort, measured by research dollars, local governments have not overlooked the utilization of science and technology in their program operations. The National Science Foundation's last survey (NSF 71–6) recited a wide array of functional applications of R. & D. by local governments, with an apparent concentration on health and hospitals, education, sanitation, and police and corrections. The allocation of dollars varied considerably from one functional area to another, however, with 39 percent going to health and hospitals, 13 percent to education, 12 percent to sanitation, 11 percent to police and corrections, 2 percent to natural resources, and less than 1 percent going respectively for highways and welfare. The latter estimates are nationwide, and if the New York City experience with the RAND Corporation were examined in contrast it would appear that in this case heavy outlays were made for "managerial" R. & D. focused upon operations analysis of productivity problems afflicting basic city services (fire, police, and sanitation). The New York experience was unique in another way, in that the RAND contingent was set up with a direct line to the Mayor through the Budget Director, instead of at the disposal of the line departments of the city government. While the New York RAND program was decidedly impressive on nearly every count, and produced outstanding policy alternatives together with some striking applied research results, its survival capacity hung by the loose thread of the incumbent mayor's personal support and it had little success in creating a supportive constituency at the departmental level. As the mayor's political strength eroded, RAND's vulnerability rose proportionately and the institution itself became a local issue. If there was a strategic mistake, it was in assigning a high profile to RAND as a symbol of the new-style American mayoralty.

More typical were the R. & D. outlays administered by operating agencies of local governments. They tended to grapple with the tedious problems of service quality and delivery. According to the National Science Foundation, a county in Florida took the R. & D. approach to developing new curriculums in science, mathematics, vocational subjects, and guidance. The New York City Sanitation Department went in for R. & D. on containerization and building design, but spent most of the money to develop a shredder for "oversized" waste. In the police and crime areas, typical R. & D. went into closed-circuit TV to transmit fingerprints, and a prototype command and control center. Since the 1968–69 NSF survey, a consortium of State-local public interest groups have formed Public Technology, Incorporated as a not-for-profit catalyst to match governmental needs with responsive sources of information or R. & D. capacity, drawing as needed on Federal, industrial, or academic know-how. Here one glimpses one of the rare institutional mechanisms of an intergovernmental character in the field of R. & D.: The State-county-municipal consortium furnishing legitimacy to PTI, and the Federal Government (NSF, of course) providing the venture capital. The PTI performance is still to be evaluated, but it has thus far achieved a notable acceptability from its State-local clientele, it has been careful to steer clear of promising and claiming too much, and it has stuck to a class of low-technology problems of the type that local governments universally share and can talk about and which are likely to have affordable if not showy answers.

This approach is one that the cities can be enthusiasts for, as evidenced by the formation of the Urban Consortium for Technology Initiatives which includes 27 large cities and 6 large counties—a user-oriented system which has NSF front-end funds. Whether PTI, in the course of time, can hang in there long enough to begin to assemble aggregated market demand for whole classes of public technology remains to be seen, but the potential for doing it is real enough. The contrast with New York's RAND group is a telling one: in the case of PTI the staffing is predominantly drawn from public service practitioners who have lived and suffered in State, county, and local governments, and their faces and credentials are recognizable to their clients. They are not the smooth young men speaking in equations or discussing "decision trees" when they drop in on a county executive to talk business, nor do they ride in squad cars or battalion chief's cars with clipboards on their laps to chart inefficiencies in operations. The emphasis is on what the customer wants, not on what is good for him. If no technological revolution at the State-local level ever results from PTI's efforts, the chances are that R. & D. will make appreciable gains on the accumulated problems of basic public services, including the problem of productivity.

The State Legislatures

A critical aspect of intergovernmental R. & D. relations concerns the capacity of state legislatures. A close look at the changing output of the legislatures will show clearly that during the last five years the calendars have featured a sharp rise in bills dealing with scientific and technical problems. From a standing start, the legislatures have valuted into an arena of policy controversy and uncertainty with no preparation to speak of. The Federal Government has been largely responsible, as it has spun off massive legislative and regulatory tasks to the States as implementing instrumentalities. A 1975 report (*Meeting the Challenge*) by the National Conference of State Legislatures carries a list of 23 examples of recent Federal legislation delegating responsibility for implementation to the States, including the Federal Coal Mine Safety Act Amendments of 1965, the Natural Gas Pipeline Safety Act of 1968, the Clean Air Act Amendments of 1970, the Federal Water Pollution Control Act Amendments of 1972, and the Safe Drinking Water Act of 1974. But even without this shower of Federal handoffs the State legislatures have been obliged to tackle a wide spectrum of scientific and technical issues which have confronted them in coastal zone management, energy facilities siting, weather modification, public health, consumer protection, and environmental impact assessment. It is an overflowing menu.

While the Federal Government has shown some awareness of the wide gap between technological workloads and legislative capacity, it has not done very much about it. Only the National Science Foundation, with its very modest resources for intergovernmental programs, has been sufficiently concerned to enter the breach. To the National Science Foundation goes the credit for advancing seed money to a handful of State legislatures for demonstration projects in equipping these bodies with basic analytic staffs with the capability of investigating scientific and technical issues which bear on legislative choices. According to the NCSL study in 1975, about a dozen States now have

some version of a legislative support office concerned with science and technology. The strongest arrangements appear to be the California Assembly Science and Technology Advisory Council and the New York Assembly Scientific Staff (created in 1971 with partial National Science Foundation funding and now supported fully by the legislature). A joint executive-legislative Science Advisory Office operates in Utah, financed by the State, and in Massachusetts in 1975 a "Science Resource Network" was begun with National Science Foundation funds to serve both houses of the legislature. In Arizona, HEW funds have provided for a Human Resources Services Staffing office to assist the legislature in the human resources sector. Similarly, but without Federal seed money, a Florida Energy Committee serves both the executive and the legislature, while funds from the Robert Wood Johnson Foundation provide Joint Health Committees servicing nine State legislatures. Fragile as some of these arrangements appear to be, their contributions to the legislative process are eye-opening. M. Frank Hersman, who until recently was the moving force in the National Science Foundation in pioneering Federal-State cooperation, was able to say in the NCSL report that the New York Assembly Scientific Staff "has coordinated numerous studies (funded by NSF, state programs, and the Assembly) on such diverse subjects as solid waste management, Lake Ontario water levels, pesticide monitoring, high-speed ground transportation, and standards for mobile and factory-produced housing. Partly as a result of professional society meetings with assemblymen the New York State Assembly passed 20 energy-related measures during the 1974 regular session."

To stretch its limited resources and obtain leverage on the situation in the legislatures, the National Science Foundation has since 1973 given modest support to the National Conference of State Legislatures to mount a Science and Technology Project as a new arm of the Conference. This project operates, with a very small staff, as a network center for all of the participating state legislatures and, in a limited way, as a clearinghouse of information under the title "Model Interstate Scientific and Technical Information Clearinghouse (MISTIC)." As the time approaches for withdrawal of NSF support, the NCSL project will require funding from NCSL itself if it is to continue. But if those Federal agencies having major responsibilities for energy and environmental policy expect State implementation of delegated authorities, they should take up where the National Science Foundation leaves off and provide the moderate support needed to capture and extend the Federal investment already made in capacity-building in the State legislatures. This is a strategic approach in intergovernmental R. & D. affairs which can pay off impressively, and with only a small investment in overhead relative to the massive benefits and costs of the operating programs.

Policy Management in the States

Turning from the legislative sector to the State executive machinery, and specifically to that most powerful arm of the executive—the Budget Office—the prospect is unbelievably bleak in terms of capacity in scientific and technical fields. As a class of administrative officials,

the State budget officers comprise a species of elite, the personification of the driving force for the modernization of the public machinery. Nevertheless, one can search the State budget offices in vain for evidence of an urge to integrate R. & D. into budgeting and planning. Few budget officers have any interest in program planning for R. & D., and rare is the budget officer who knows what R. & D. funds are being spent in his State. The situation has been captured admirably by Donald Axelrod of the State University of New York at Albany in the draft of a paper prepared for an NSF-sponsored workshop at the 1975 meeting of the National Association of State Budget Officers, and from which the following is excerpted:

For all the planning activity there is only sporadic and fragmentary attention in individual plans and budgets to the use of research and technology in solving the problems of the States. The assessment of the role of technology is simply not an integral part of State planning and budgeting processes. As far as can be ascertained, no mechanisms have been developed to review systematically the entire spectrum of State programs in order to forecast the impact of technology on these programs, to identify opportunities for the effective use of technology in the light of the needs of the State, and, on a priority basis, to fund and apply technology in the solution of specific problems. Only on an ad hoc basis, and primarily in some of the health fields and in the use of computer technology have the States formulated specific criteria to guide them in the selection of appropriate technology. There appears to be inadequate recognition of the need in program planning for a systematic, rigorous and balanced assessment of the costs, benefits and risks of alternative technologies, taking into account social and economic consequences, technical and economic feasibility, the likelihood of achieving worthwhile results within a reasonable time and the overall impact on human beings and the physical environment.

The foregoing is a fair statement of how matters stand in the budget and planning machinery of the States. From the perspective of the budget officers, however, the scene looks different. R. & D. are small potatoes in the State budget, and are the concerns of the program agencies. The role of the budget officer is to analyze the merits of budget requests which come to him, and to defend the governor against being sold a bill of goods in the guise of science and technology. It is also the budget officer's business to advise the governor and the agencies on performance criteria, and to press for higher productivity and cost savings.

Science and technology, or more accurately, R. & D., do not appear to the State budget officers to be strategic tools of the kind that a governor needs to manage the official business of the State. In their view, R. & D. are functions embedded in program requirements, and they are taken care of by program administration. A few years ago, the writer of this paper asked a few of the ablest of the State budget officers how they would utilize a hypothetical ten new analysts if they were given the chance, and in no case would they have given priority to strengthening the R. & D. oversight resources of their offices. The writer later met with NASBO at one of its annual meetings, and in a plenary session asked three questions of the assembled budget directors. The first question was how many of the budget officers knew what their State expenditures for R. & D. were. Not one hand was raised. The second question was how many could get the information if given three weeks to do so. A single hand was raised. The final question was how many thought the information would be useful, and three hands went up hesitantly. Clearly, an innovation such as a State R. & D.

budget plan has no takers. Equally clearly, R. & D. is not a subject of much conversation among budget officers across State lines, nor between the budget officers and the Federal OMB. There is a striking disjunction between the "State of the State" message of the governors, with their emphasis on issues of health and energy and the environment and development, and the budget messages with their emphasis on costs, efficiency, and taxes. In any analysis of the barriers to intergovernmental R. & D. relations, the indifference of the States budget officers has to be taken seriously. Their role in the changing dynamics of intergovernmental relations is a vital and central one, and without their participation the work of capacity-building in State government will go slowly.

The point of this discussion is not that State budget officers are a class of primitives who are blind to the values of R. & D. The argument is one of roles and opportunities, and how they are viewed from where budget officers sit. Harold A. Hovey, who until recently served as budget director in Illinois, said to the NASBO conferees this year that the "basic question" was whether the central management agency should take a "promotional stance" toward science and technology. He observed that the question had to be considered in the context of all the other things that such an office promotes: program experimentation, program evaluation, improved management systems, better information systems, improved budgeting and financial management systems, etc. Then he concluded that "in the context of these other promotions, I do not feel that the central management agency needs to take a strong promotional stance for science and technology. Given the fact that State budgeting agencies do not run line agencies and that line agencies have a tendency to make cost-cutting technology be cost-increasing (e.g., computers and audio-visual aids), a promotional stance *may compromise the budget function*" [emphasis added]. That is perhaps what it comes down to. R. & D. is suspected in all budget offices to be a cost-push type of expenditure: once the results of R. & D. enter the budget base they lift the level of base costs another notch, and the promised "savings" never quite materialize. This image of R. & D. as a factor in conflict with cost containment rarely comes out in the open, but it is surely very close to the surface of the perceptions of budget controllers. Though they will not openly oppose the introduction of new technology, they will hardly become its champions. Advocacy is not known to be a role of budget officers at any level of government, and from all the present signs the States are not about to break the pattern for the sake of intergovernmental relations in R. & D.

The case for injecting R. & D. capability into State budget offices goes beyond the issue of advocacy or "promotion." It goes to the quality of decisionmaking. If a State legislature can profit from staff capabilities in examining alternative policy choices involving science or technology, it follows that the budget offices (or "central management agencies") have no less need and as much potential to profit. Certainly they should have the incentive. A generalist staff can judge *whether* the experts know what they are talking about, but not *what*. If a governor wishes to go beyond his line agencies to find independent options, he needs the staff capability to help him make up his mind. His budget and planning office should provide that capability, but it cannot be forced upon officials who want no part of it.

Still, when the incentives are present the States and the Federal Government can get together on R. & D. for policy planning. The prime illustration probably is the "Texas Energy Advisory Council Research Project," established by the Governor to develop policy options and recommendations in six energy areas (1) energy supply stimulation and demand conservation, (2) environmental and noneco-omic issues, (3) legal and regulatory problems, (4) State R. & D. strategies, (5) transportation technology alternatives, and (6) utilization of results. Between 1974 and 1975, an apparent total of $1.3 million went into the project, of which $624,000 came from Nation Science Foundation's "Research Applied to National Needs" program. State agencies put in $345,000, universities $280,000, and private organizations $60,000. According to a gratified NSF, the project has paid off handsomely, with five major pieces of State legislation enacted (geothermal production, utilities regulation, mass transit, energy efficiency labeling, and machinery for policy management and coordination). NSF also reports that the Texas project reports received national attention and were distributed to over 400 organizations including State agencies in 11 States. Seen at a distance, this experience suggests that a Federal-State R. & D. relationship can quickly take shape and have a measurable payoff when the necessary factors come into convergence: an acute state need, an overriding national interest, political sensitivity, timing, plentiful funds, and a readiness to utilize results. Crisis is always a powerful motivator for R. & D., and it works as well in intergovernmental relations as in their absence, particularly if a catalyst such as a RANN program is available and on its toes.

The Limits of Technology Transfer

Intergovernmental relations in R. & D. are complicated enough without the added myths surrounding them. One of the persistent myths is the overselling of "technology transfer" as a panacea for State and local governments. There indeed is a potential for sharing Federal technology with other units of government, but it is a limited potential, not an open-ended one. It is limited by an array of factors: the principal one consisting of the fact that federal technology results from Federal agency requirements, not from those of State and local users. Other factors include the "dumping" mentality of federal technology transfer organizations, the absence of competent market research as a prerequisite to technology sharing, differences in sophistication between sellers and users, cost barriers, and failures to recognize the long lead times involved in the necessary stages of technology modification and demonstration. A general appraisal of the accumulated experience with intergovernmental technology transfer would reach the conclusion that it has been disappointing and that it is not likely to get very much better under existing premises and approaches. While there are examples of successful spinoff, close analysis tends to show that they are in the regions of low and intermediate technology and in functional areas where there is a close professional affinity between Federal and State-local agencies, notably health, highways, and law enforcement. The contrast between intergovernmental technology transfer on the one hand, and the diffusion of innovation in the private sector on the other, is striking. In the latter case, involving

normal commerce between buyers and sellers, the innovation is embedded in a product or process and the method of transfer or diffusion is the sales or marketing mechanism which provides a comparative choice within parameters of customer preferences, price variances, and competition. The problem with intergovernmental technology transfer is that government does not pursue innovation for the same reasons as a market economy, but to accomplish some assigned mission whose objectives have nothing to do with innovation per se. Spin-off in innovation is an afterthought, not a forethought. Moreover, the Federal technology was not planned or designed with close familiarization with State and local user requirements. To finish it all off, the Federal employees who are charged with technology transfer seldom if ever have the skills in management and marketing which are so central to the diffusion of innovation in the market economy.

Plainly, State and local governments are not going to inherit the earth via the route of technology transfer. Throwing Federal technology indiscriminately at their problems will only make their situation more unmanageable. We can expect a steady but low level of technological diffusion from existing practices and arrangements, bolstered by such catalysts or brokers as Public Technology, Inc., and by some gradual enlightenment of Federal marketing techniques, but not much more. For long-term gains in intergovernmental relations, the technology transfer idea will have to be restructured to base Federal civilian R. & D. upon joint planning and design with state and local groups who will be participants as well in stage-by-stage assessment of R. & D. performance and end-product testing. If these arrangements are followed, the final users will have a built-in stake in eventual application and diffusion. Otherwise, they will remain cold customers.

A Neglected Federal Option

One of the conspicuously missing elements in the intergovernmental relationships of R. & D. is the network of Federal laboratories and research centers. The term "network" unfortunately is itself inaccurate, since the Federal laboratories exhibit hardly any network characteristics. We have a vast and costly array of these facilities, created largely but not entirely for defense, atomic energy, and aerospace purposes. They number in the high hundreds, employ some 120,000 trained individuals, and are scattered across 32 States. They range from large and sophisticated R. & D. centers to very small specialized laboratories and experimental stations. Their aggregate budgetary costs range into billions of dollars. This is a massive scientific and technical enterprise held in public ownership for Federal purposes. The question here is whether a sensible intergovernmental relations policy for research and development should not provide free access to those advanced R. & D. centers for State and local governments. As the Nation's domestic priorities focus on energy, health, natural resources, and governmental productivity, and as the initial objectives of the Federal R. & D. centers assume less intensity under current international policies, the case for a multipurpose reorientation of these facilities grows stronger. If the State and local governments generally lag in scientific and technical capacity, as appears to be the case, it makes considerable sense to look to the Federal labora-

tories as backstopping centers for R. & D. support and technical assistance.

This argument was first advanced at the time of the 1972 Message on Science and Technology by the President, and small gestures were made to implement it, with commensurately small enthusiasm. With the encouragement of National Science Foundation, a Department of Defense Laboratory Consortium was informally assembled to provide limited technical services to civilian agencies and state-local governments. This represents the only network in existence, comprising 25 DOD facilities, and subsequently augmented by NASA and some civilian agency R. & D. centers, for a combined array of about 50 facilities. Surveying the outputs, one finds that the consortium has delivered technical services in areas of mine safety, air traffic control, passenger vehicle safety, medical instrumentation, fire control, law enforcement, rehabilitation, and medical diagnosis. On the State and local side, some defense laboratories have helped with joint research on pollution control and abatement. While the performance is less than spectacular, it is enough to confirm the utility of laboratory involvement in State and local problem-solving. It has not been enough, however, to stir the Federal policymakers into action. As things presently stand, the Federal laboratory consortium is breathing hard and going noplace. The predicament has been described accurately in a paper by Sherman Gee, which reads in part as follows:

> Although there is room for an expanded DOD effort, there exist other constraining influences. One is the absence of incentives on the part of DOD laboratory managers to become involved in technology transfer activities. No extra recognition or credit can be expected, and only the personal satisfaction of having helped alleviate some of our social ills is offered * * * Technology transfer is viewed all too often as having little more than nuisance value to the busy line manager * * * DOD technology transfer to date has been oriented mainly toward other Federal, State, and local government institutions as potential technology users, with insufficient attention to industry. This * * * stems partially from trying to avoid situations which may create conflicts of interest * * * the transfer of public-owned technology to the private sector is where the great promise of DOD technology transfer lies.

The problem, however, is not only missing incentives. Disincentives also must be reckoned with. The DOD-civil agencies consortium has never gotten off the ground because it has been restrained, even leashed, by policy rulings. Current DOD policy guidelines read this way:

> The expenditure of in-house effort in any one laboratory shall be limited to 3 percent of professional personnel * * * unless express approval of the parent military department is granted to exceed this limit.
>
> The DOD commitment to support the brokerage function at the National Science Foundation shall not exceed 2 man-years per year through fiscal year 1976, subject to the continued willingness of the Military Departments to absorb the costs.

With such grudging guidelines as these, the Federal laboratories are held in check from providing the technical services which State and local governments could put to good use. Vast Federal R. & D. centers occupy the territory of the States, unable to contribute to the needs of the host governments because of Federal manpower and budget restrictions—and, in all likelihood, because of apprehension of policymakers that congressional fury will be turned on them if the laboratories are caught doing something that has not been formally

legitimized. So Federal policy drifts, and a superb R. & D. resource is withheld from intergovernmental usage.

This writer will argue that the issue of the Federal R. & D. centers actually goes beyond the question of potential benefits to State and local governments. The day is past when these facilities can be regarded and administered as a balkanized scatter of technical enterprises which are locked into the frameworks of various "owning" agencies. By any reasonable standard of systems management, they should be assembled into a unified science and technology system. They constitute a rich and valuable national resource, both physical and human, and it is in this light that they deserve to be integrated into major and minor networks and utilized flexibly under a single management system for a variety of governmental and industrial purposes. It would then be possible to have clusters of laboratories compete with each other for mission assignments and to produce and diffuse R. & D. results. They could engage in joint R. & D. with industrial organizations and State or local governments, and some of the R. & D. centers could be spun off as institutes of technology which could stimulate regional capacity-building and regional development. Indeed, this pattern has been used in Great Britain for some years, notably in the case of the primary atomic energy laboratories at Harwell.

If this prescription finds no takers, the more conservative option remains. This is the option of legislation to legitimize the multipurpose use of Federal R. & D. centers as technical assistance facilities for State and local governments and to authorize them to engage in joint R. & D. and consultative services with these governments as an explicit and appropriate form of intergovernmental cooperation. This is one of the few immediate, tangible, and sensible steps that can be taken to recognize that there is an intergovernmental dimension to research and development.

Conclusions

Research and development are, at the present time, peripheral aspects of intergovernmental relations. Trace elements of the massive Federal involvement in science and technology can be detected in the operations of State and local governments, and patches of State and local awareness and activity appear here and there as exceptions to the general picture of low R. & D. vitality. Through the persistence of the National Science Foundation, however, the institutional capabilities of State and local government for coping with scientific and technical aspects of problems of choice have been significantly upgraded.

Where to go from here is the tough question. Throwing R. & D. dollars at State and local governments as an impulsive act of faith cannot be justified as a policy choice. The flow of general revenue sharing has turned up no evidence that State and local decisionmakers view investment in R. & D. as a priority use of discretionary revenues. The managerial capacity of most State and local governments for planning and executing R. & D. are not such as to inspire high confidence.

The assumption continues to be workable, however, that the pyramiding dilemmas and frustrations of State and local government can be relieved if the R. & D. resources of the Federal Government can be

coupled in a productive way with the State and local users. This writer believes that if *process* is emphasized as the key to intergovernmental relations in R. & D. a productive role for State and local governments can be carefully worked out over time. We have been emphasizing the wrong things—R. & D. as a self-fulfilling prophecy, State and local spending on R. & D., and technology transfer as a species of Federal surplus property disposal. We do not have much to show for it to date, nor any reason to expect better results in the future.

If the objective is to expedite and increase the diffusion of know-how and technology through intergovernmental arrangements, some barriers will have to come down and some catalysts be provided. One barrier is the idea that "R. & D." means high technology; in the case of State and local government it is more likely to mean low or intermediate technology. A second barrier is the sparse representation of State-local operating experience in Federal R. & D. agencies. A third is the lack of incentives for Federal agencies to assign strong weights to State and local needs and preferences, relative to Federal mission requirements, in shaping R. & D. programs. A fourth is the poor-to-moderate capacity of many State and local governments for judging the risks and benefits of applied science and technology, and the inadequate resources of National Science Foundation for improving their capacities. And a fifth barrier is the resistance at the Federal level to making the technical services of its laboratories and technology centers generously available to State and local governments for joint R. & D. and problem solving.

In the long run, the largest benefits of Federal R. & D. will result from enabling State and local governments to exercise meaningful leverage on the Federal Government's outlays for R. & D. in the civil areas. If this is going to happen, a process must be introduced which gives the States and localities an effective voice in programing. This requires leadtimes of 1 to 3 years, and even longer waiting times for the results to be evaluated and put into practice. If this does not come as good news, there is no help for it. R. & D. have time cycles which must be understood, even by elected officials who want answers in time to impress the voters. Intergovernmental relations in R. & D. are different from other kinds of intergovernmental relations, and the reason for it is found in the built-in uncertainty of research and development. Perhaps this has a lot to do with the unimpressive performance of R. & D. as a fast-response remedy to social problems. Put very simply, R. & D. comes under the head of *investment*, not current expense. By leveraging the Federal investment, State and local governments can expect deferred but potentially high yields.

In the shorter run, intergovernmental policy strategies should emphasize a variety of catalysts for the diffusion of R. & D. into and among State and local governments. Primary among them is the strengthening of know-how and analytical capacity in the Governors' planning offices and in the legislatures. "Brokerage" arrangements for communication and the matching of users and providers, such as the Science and Technology arm of the National Conference of State Legislatures, regional cooperative-consortiums of States and cities, and PTI, are solid candidates for further support and diversification with the role of the National Science Foundation being augmented by

ERDA, EPA, and HEW. The potential of the Federal R. & D. centers as catalysts for technical assistance should be recognized and legitimized as a strong and geographically dispersed capacity in-being for regional public service. Taken together, these combined actions would constitute a pragmatic and low-cost start towards assembling the elements of an intergovernmental relations strategy for R. & D.

FEDERAL SUPPORT OF R. & D. ACTIVITIES IN THE PRIVATE SECTOR

By Edwin Mansfield

1. Introduction

This paper, prepared for the Congressional Research Service at the request of the Joint Economic Committee of the Congress, is concerned with the following questions: To what extent does the Federal Government support research and development (R. & D.) in the private sector? How is this support distributed among industries, universities, research centers, and other organizations? What incentives are there for private recipients to control costs or improve the efficiency of federally funded R. & D. activities? Why is support of this kind regarded as being in the public interest? What measurements have been made of the social benefits of additional investments in R. & D., both in agriculture and industry? Is there any evidence of an under-investment in particular types of civilian technology? What mechanisms of government support have been used in other countries, such as Japan, France, and the United Kingdom? In the United States, what are the major advantages and disadvantages associated with each of the mechanisms for Federal support of private sector R. & D.? What are some possible approaches to improving the effectiveness of Federal programs in support of R. & D. in the private sector?

Needless to say, we shall have to treat many of these questions rather cursorily in order to keep the paper to a reasonable size. For those who want to pursue some points or issues in more detail, a rather lengthy set of references is included. Also, to prevent confusion, it is important to define at the outset what we mean by "research and development" and by "the private sector." The National Science Foundation's definition of research and development is used here. National Science Foundation includes basic research, applied research, and development as parts of research and development. Basic research is defined as "projects which represent original investigation for the advancement of scientific knowledge and which do not have specific commercial objectives * * *."[1] Applied research includes "projects which represent investigation directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes."[2] Development includes "technical activity concerned with nonroutine problems which are encountered in translating research findings or other general scientific knowledge into products or processes. It does not include routine technical services to customers * * * [or quality control, routine product testing, market research, sales promotion, or sales service]."[3] As for the private

[1] See National Science Foundation, *Methodology of Statistics on Research and Development*, 1959, p. 124.
[2] *Ibid.*
[3] *Ibid.*

sector, we regard all privately owned firms and nonprofit organizations as belonging to the private sector. However, we recognize that some such firms and organizations do a heavy volume of business with the government and are so closely linked with government agencies that the distinction between the private sector and the public sector can be somewhat blurred.

2. Federal Contracts and Grants for Research and Development

To begin with, we must look briefly at the present extent and pattern of Federal support of R. & D. activities in the private sector. An important part of this support is encompassed by Federal contracts and grants for research and development. As shown in table 1, total expenditures in the United States for R. & D. were about $32 billion in 1974, of which about $17 billion were financed by the Federal Government. Thus, about 53 percent of our Nation's R. & D. expenditures were financed by the Federal Government in 1974, and much of this federally financed R. & D. was carried out by the private sector. As shown in table 1, government laboratories carried out only about 30 percent of federally financed R. & D. About 50 percent of federally financed R. & D. was carried out by industry.

Federal R. & D. expenditures are concentrated heavily in a relatively few areas. In 1972, as shown in table 2, almost $9 billion was spent on defense R. & D., and almost $3 billion was spent on space R. & D. Health R. & D. accounted for about $1.4 billion, and energy R. & D. accounted for about $0.4 billion. Other areas where significant amounts of federally financed R. & D. took place were environmental protection, transportation, agriculture, and education. A considerable amount was spent by the Federal Government on the general advancement of science and technology. Despite the fact that defense and space R. & D. were a smaller percentage of total federally financed R. & D. than they were a decade before, they still constituted about 70 percent of the total.

The extent to which various Federal agencies perform R. & D. outside government laboratories differs considerably. As shown in table 3, the Department of Defense performs about one-fourth of its R. & D. in government laboratories; most of the remainder is performed by industrial firms. Similarly, NASA performs about one-quarter of its R. & D. in government laboratories; the rest is performed largely by industrial firms. On the other hand, the AEC (now ERDA) performed the bulk of its R. & D. in federally funded research and development centers (like Oak Ridge, Sandia, Brookhaven, and Los Alamos), some of which are administered by firms, some by universities. And other agencies, like the Department of Agriculture and the Department of Commerce, perform most of their R. & D. in their own laboratories.

There are also very substantial differences among industries in the extent to which the R. & D. that they perform is financed by the Federal Government. As shown in table 4, in 1973 the Federal Government financed about 80 percent of the R. & D. in the aircraft industry, about 50 percent of the R. & D. in the electrical equipment industry, and about 20 percent of the R. & D. in the instruments industries. These are the industries where the largest share of the R. & D. performance is federally financed. On the other hand, in the chemical,

petroleum, drug, rubber, primary metals, and food industries, among others, the percentage of R. & D. performance that is federally financed is much smaller. Thus, just as federally financed R. & D. is concentrated in a few areas, so federally financed R. & D. tends to be concentrated in a relatively few industries.

TABLE 1.—SOURCES OF RESEARCH AND DEVELOPMENT FUNDS AND PERFORMERS OF RESEARCH AND DEVELOPMENT BY SECTOR, UNITED STATES, 1974

[In millions of dollars]

Source of R. & D. funds	Research and Development performance				
	Federal Government	Industry	Colleges and universities	Other nonprofit organizations	Total
Federal Government	4,900	[1] 8,320	[1] 2,883	[1] 852	16,955
Industry		13,700	96	120	13,916
College and universities			683		683
Other nonprofit organizations			211	280	491
Total	4,900	22,020	3,873	1,252	32,045

[1] Includes associated federally funded research and development centers. According to the National Science Foundation, such centers accounted for about $600,000,000 of Federal R. & D. obligations administered by industry, about $800,000,000 of Federal R. & D. obligations administered by colleges and universities, and about $200,000,000 of Federal R. & D. obligations administered by other nonprofit organizations.

Source: National Science Foundation, "National Patterns of R. & D. Resources," Washington, 1975.

TABLE 2.— FEDERAL RESEARCH AND DEVELOPMENT EXPENDITURES FOR SELECTED FUNCTIONS, 1965 1970 AND 1972

[In millions of dollars]

Function	1965	1970	1972
National defense	7,179	8,067	8,703
Space	4,638	3,597	2,960
Health	663	1,164	1,387
Advancement of science and technology	372	590	705
Environment	213	370	509
Transportation	198	451	607
Energy conversion and development	281	341	405
Agriculture	169	239	288
Economic security	42	144	154
Education	19	94	126

Source: "Science Indicators," National Science Foundation, 1973.

TABLE 3.—FEDERAL OBLIGATIONS FOR RESEARCH AND DEVELOPMENT IN MAJOR AGENCIES, BY PERFORMER FISCAL YEAR 1973 [1]

[In millions of dollars]

Agency	Intramural	Industrial firms	Colleges and universities	Total
Department of Agriculture	248	2	90	361
Department of Commerce	123	51	42	228
Department of Defense	2,421	5,734	219	8,774
Department of Health, Education, and Welfare	370	94	1,002	1,957
Department of the Interior	142	64	30	256
Department of Transportation	118	185	20	381
Atomic Energy Commission [2]	16	238	89	[3] 1,375
National Aeronautics and Space Administration	899	2,077	130	3,275
National Science Foundation	20	6	435	526
Total	4,598	8,683	2,126	17,791

[1] These figures were estimated in late 1972.
[2] Now Energy Research and Development Administration.
[3] Almost $1,000,000,000 was spent in federally financed research and development centers administered by firms or universities.

Source: "Federal Funds for Research, Development, and Other Scientific Activities," National Science Foundation, 1972.

TABLE 4.—FUNDS FOR RESEARCH AND DEVELOPMENT PERFORMANCE, BY INDUSTRY AND SOURCE, 1973

[In millions of dollars]

Industry	Industry financed	Federally financed	Total
Food and kindred products	268	2	270
Textiles and apparel	63	1	64
Lumber and furniture	(1)	(1)	55
Paper and allied products	197	1	198
Industrial chemicals	940	191	1,130
Drugs and medicines	(1)	(1)	618
Other chemicals	(1)	(1)	330
Petroleum refining and extraction	490	14	504
Rubber products	251	33	285
Stone, clay, and glass products	173	3	176
Primary metals	262	11	273
Fabricated metal products	255	12	267
Machinery	1,806	334	2,141
Electrical equipment and communication	2,678	2,652	5,330
Motor vehicles	2,035	402	2,437
Aircraft and missiles	1,090	3,961	5,051
Professional and scientific instruments	721	176	896

[1] Not separately available but included in total.

Source: Science Resources Studies Highlights, National Science Foundation, Dec. 4, 1974.

Turning from industry to the universities, it is also clear from table 1 that our Nation's colleges and universities are heavily dependent upon the Federal Government for R. & D. funds. About three-fourths of the R. & D. carried out by the colleges and universities is financed by the Federal Government. The leading source of these funds is the Department of Health, Education, and Welfare. Table 5 shows the 40 universities that received the most Federal obligations for R. & D. in 1973, and the amount each received. As would be expected, the leading research-oriented universities, such as MIT, Harvard, Berkeley, Michigan, and Stanford, tend to rank among the highest. In 1973, the 100 universities and colleges at the top of this list received about 85 percent of the total Federal obligations to colleges and universities. Since the mid-1960's, there has been some pressure to allocate such funds more evenly.

3. Federal R. & D. Contracts and Grants: Rationale and Incentives for Efficiency

Given that Federal R. & D. contracts and grants to the private sector amount to over $12 billion per year, it obviously is important that we consider the reasons why support of this kind is in the public interest. The rationale for such support varies from one area of support to another. Many of the areas characterized by relatively large amounts of federally financed R. & D. are intended to provide new or improved technology for public sector functions. National security and space exploration, for example, are public goods—goods where it is inefficient (and often impossible) to deny their benefits to a citizen who is unwilling to pay the price. For such goods, the Government is the sole or principal purchaser of the equipment used to produce them; and since it has the primary responsibility for their production, it must also take primary responsibility for the promotion of technological change in relevant areas. Even though much of the R. & D. of this type is performed by the private sector, it is important to note that the primary objective of this R. & D. is not to promote technological

change in the private sector but in the public sector. Although there is unquestionably some beneficial spillover, the benefits to the private sector seem decidedly less than if the funds were spent directly on private sector problems.[4]

TABLE 5.—*Total Federal obligations for R. & D. to the 40 universities and colleges receiving the largest amounts, 1973* [1]

Rank and university	Millions	Rank and university	Millions
1 MIT	$114	21 USC	$22
2 University of California, San Diego	49	22 University of California, San Francisco	22
3 Stanford	46	23 Colorado	21
4 Harvard	46	24 Duke	20
5 University of Washington	45	25 Rochester	19
6 University of Wisconsin, Madison	44	26 Yeshiva	19
7 UCLA	44	27 Cal Tech	18
8 Berkeley	41	28 Purdue	18
9 Columbia	41	29 University of Miami	18
10 Michigan	37	30 University of Texas, Austin	16
11 Johns Hopkins	35	31 University of California, Davis	16
12 Minnesota	32	32 Utah	16
13 Cornell	31	33 Pittsburgh	16
14 Chicago	31	34 Penn State	16
15 Yale	30	35 UNC	15
16 Pennsylvania	29	36 Baylor	15
17 University of Illinois, Urbana	28	37 Iowa	14
18 NYU	25	38 Case-Western	14
19 Washington University	23	39 Northwestern	14
20 Ohio State	22	40 Hawaii	14

[1] Of course, not all of these universities and colleges are in the private sector. According to the National Science Foundation, about 40 percent of total Federal obligations went to private colleges and universities.

SOURCE: National Science Foundation. Federal Support to Universities, Colleges, and Selected Nonprofit Organizations, Washington, 1975.

In other cases, the rationale for large federally financed R. & D. expenditures is some form of market failure. In the case of energy, for example, it has been claimed that the social returns from energy R. & D. exceed the private returns because of the difficulties faced by a firm in appropriating the social benefits from its R. & D. Also, it has been argued that risk aversion on the part of firms may lead to an under-investment (from society's point of view) in R. & D. Further, the availability of energy is frequently linked to our national security.[5] In the case of agriculture, the fact that farms are relatively small productive units has been used to justify federally financed R. & D. The argument that farms are too small to engage in an efficient R. & D. effort certainly was more compelling when there were fewer and smaller industries supplying agriculture. But according to many experts, there still seem to be important aspects of farming that are not reflected in obvious markets for these suppliers.

Finally, as we saw in table 2, some federally financed R. & D. is directed toward the general advance of science and technology. Such expenditures seem justified because the private sector will almost certainly invest less than is socially optimal in basic research. This is

[4] See Mansfield [25], pp. 224–28. Mathematica [33] has carried out a study, based on the sort of techniques discussed in section 6 (and illustrated in figure 1), to estimate the returns to the civilian economy from several NASA innovations. The results indicate that these innovations resulted in benefits to the civilian economy amounting to about $7 billion.
[5] For example, see Tilton [60].

because the results of such research are unpredictable and usually of little direct value to the firm supporting the research, although potentially of great value to society as a whole. In other words, basic scientific information has many of the characteristics of a public good.[6]

Incentives for efficiency

We shall return to the question of the rationale for Federal support of R. & D. in the private sector; but for now, we turn our attention to the incentives for efficiency and cost reduction in federally financed R. & D. In a free enterprise economy, there are important incentives for efficiency, one of the most important being that a firm can increase its profits (or reduce its losses) by reducing its costs. In other words, since firms under normal market conditions use fixed price contracts, increased efficiency means increased profit. Unfortunately, such incentives, which are so important in most areas of the economy, cannot be transferred at all easily to research and development, because R. & D. is so risky that fixed price contracts are generally not feasible. It is very difficult to establish a contract whereby the contractor agrees to obtain a certain quantum of information or to develop a certain product or process for a fixed price, because it is so difficult for the contractor to estimate how much it will cost to achieve this result. Thus, many government contracts for research and development are basically geared to reimburse the contractor for whatever his costs turn out to be (within reason) to achieve the desired result. As is well known, these costs often tend to be much higher than are initially estimated. Alternatively, for some types of R. & D., a certain contract amount is stipulated, and the contractor is expected to achieve as much as he can with that amount. In either case, the incentives for reducing costs undoubtedly are less than they would be if a fixed price contract of the ordinary sort were feasible.

However, this does not mean that there are no incentives for efficiency. In particular, if the award of new contracts is known to depend, at least in considerable part, on past performance, this can be a very important incentive. But for this incentive to operate, at least two conditions must be met. First, the contracting government agency must be in a position to judge the contractor's performance reasonably well. Clearly, this is not as easy as it may seem, since apparent failure may be due as much to luck as to lack of skill, and since the product of a research project may be difficult even for leading experts to evaluate. Second, there must be a reasonable amount of competition among potential contractors. If the Government allows itself to get locked in to particular contractors, this incentive cannot operate at all well. Based on the studies at RAND,[7] by Peck and Scherer,[8] and by others, the problem of creating adequate incentives for efficiency in government funded R. & D. carried out in the private sector is very real and very difficult to solve in anything other than a very approximate way. Certainly, however, the Government should make sure that reasonably objective and unbiased judgments are made of contractor and grantee performance and that competition is en-

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[6] See Arrow [1] and Nelson [43].
[7] For example, see Klein [22] and Marschak, Glennan, and Summers [32].
[8] See [52].

couraged wherever possible. Although these steps will not solve the problem, they will certainly be a step in the right direction.[9]

4. Patents, Tax Incentives, and Other Existing Policy Instruments

Federal contracts and grants for R. & D. are by no means the only way in which the Federal Government currently supports R. & D. activities in the private sector. In this section, we provide a brief (and necessarily sketchy) description of some of the other important ways that the Federal Government provides such support.

The Patent System

The U.S. patent laws grant an inventor exclusive control over the use of his invention for 17 years, in exchange for his making the invention public knowledge. Proponents of the patent system argue that these laws are an important incentive for invention, innovation, and early disclosure of new technology. Critics of the patent system stress the social costs arising from monopoly and question the importance of patents as an incentive in many parts of the modern economy. Few critics, however, would go so far as to say that the patent system does not encourage additional R. & D. in at least some parts of our economy.[10]

Tax Laws

The tax laws provide some stimulus for private R. & D. If the tax treatment of investment in plant and equipment and in R. & D. were neutral in terms of its effects on incentives, R. & D. would be classified as a capital investment, and depreciated over its useful life. Instead, our tax laws allow R. & D. expenditures to be treated as current expenses, which means that they are made more profitable relative to other forms of investment. Another provision of the Internal Revenue Code allows the sale of patents to be taxed at capital gains rates (which generally are lower than ordinary rates), even if the person is a professional inventor and in the business of making and selling patentable inventions.[11]

Regulation

Some aspects of Federal regulation seem to encourage R. & D. activities in the private sector. For example, with regard to the airlines, it has frequently been concluded that attempts to keep prices above the competitive equilibrium level have resulted in a high rate, perhaps too high a rate, of technological change and innovation. Obviously, however, this is not true of all regulated industries. For example, in the railroad industry, it is frequently claimed that regulation has dampened research and innovation, e.g., in the case of the Big John covered hopper grain cars. Despite recent studies of the Averch-Johnson effect, regulatory lag, and a variety of other relevant

[9] But the competition obviously should be real, not just a facade. The encouragement of many proposals that have no chance of being accepted to give the appearance of competition merely results in additional social waste. See [28].
[10] See Markham [31] and Scherer [56]. For a British study, see C. Taylor and Z. Silberston, *The Economic Effects of the Patent System*, Cambridge, 1973.
[11] See Weidenbaum [62].

considerations, we know very little about the effects of various kinds of regulation on R. & D. in the private sector. This is unfortunate since about 10 percent of the Nation's gross national product arises from the regulated industries, and since regulation has effects throughout the economy.[12]

Antitrust

Our Nation's antitrust policies seem to have important effects on research and innovation in the private sector. Although the evidence is limited, it appears that relatively strong competition tends to promote research and development, so long as firms are above some threshold size. Since it appears that new entrants are often significant sources of innovation, it seems important to eliminate unnecessary barriers to entry. However, the effects of antitrust policy are certainly not unmixed. For one thing, antitrust policies may cut the incentive of the dominant firm (or firms) in an industry to generate relatively rapid technical advance. Also, the fact that antitrust policy is at odds with the patent system may in some cases reduce the incentives for R and D in some industries.[13]

Technology Transfer

The Government currently invests in a number of activities to transfer the results of government R. & D. to the private sector. To the extent that these activities are effective, they are likely to encourage private R. & D. Perhaps the best known of these activities is NASA's technology utilization program. This program has included a number of research institutes and universites. For example, the Midwest Research Institute and the Aerospace Research Applications Center at Indiana University have received information concerning technological developments in the space program, and disseminated them to private industry. The success and effectiveness of this dissemination program, and others of a similar type, are difficult to measure.

Education

The Federal Government's policies to support education (in science and technology, and other fields as well) also encourage R. & D. in the private sector. Clearly, the extent of private R. & D. is determined in part by the quantity and quality of scientific and engineering talent available in the society. Further, better educated managers and workers seem to be better able to utilize research results, and more inclined to invest in R. & D. The links between education, science, and technology are important, and the Federal Government's attempts to strengthen education certainly have helped to support R. & D. in the private sector.[14]

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[12] See Capron [5], Mogee [37], and Noll [46].
[13] See Scherer [56], Markham [31], and Noll [46].
[14] See Mansfield [30] and references cited there.

5. The Basic Economics of Government Support of Civilian Technology

In recent years, economists have made some attempt to determine, on the basis of general economic theory, whether it is likely that existing Federal programs in support of civilian technology are adequate. In this section, we summarize some of the arguments bearing on this question. To begin with, it is generally agreed that, because it is often difficult for firms to appropriate the benefits that society receives from new technology, there may be a tendency for too few resources to be devoted to the development of new technology. It is also generally agreed that the extent to which these benefits are appropriable is probably related to the extent of competition faced by the potential innovator and to the kind of research or development activity in question. In particular, the more competition there is and the more basic the information, the less appropriable it is likely to be. However, this argument is blunted somewhat by the obvious fact that some inventive activity is carried on with little or no economic motive. Clearly, inventors and technologists are not motivated solely by dollars and cents.

Economists seem to agree that, because R. & D. is a relatively risky activity, there may be a tendency for firms to invest too little in it, given that many firms seem to be averse to risk and that there are only limited and imperfect ways to shift risk. On the one hand, if firms are big enough so that their R. & D. program is reasonably large compared to particular projects, uncertainty is likely to be handled more effectively. On the other hand, since the threat of competitive innovation is an important stimulus to make firms more willing to accept the uncertainties involved in R. & D., there are obvious disadvantages in firms becoming too large relative to the total market. In any event, it seems to be generally agreed that the riskiness of R. & D. is likely to result in less R. & D. than may be socially optimal.

Still another reason why there may be an under investment in particular kinds of R. & D. is that they may be characterized by significant indivisibilities. In other words, they may be characterized by economies of scale that prevent small organizations from undertaking them efficiently. This argument seems much more applicable to development than to research. It is important to recognize that, while firms may have to be a certain minimum scale to do many kinds of R. & D. effectively, this scale may be a relatively small share of the market. Furthermore, it is important to recognize that small firms have been responsible for many important innovations, while many big firms have concentrated on more minor improvement innovations. Nonetheless, bearing these qualifications in mind, it is often argued that some industries are so fragmented, they cannot do the proper amount of R. & D.[15]

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[15] For a discussion of the considerations involved in this and the previous two paragraphs, see Noll [46].

While the preceding arguments have a considerable amount of force, they by no means prove that there is presently an under investment in civilian technology. For one thing, these arguments generally are based on the supposition that markets are perfectly competitive, whereas in fact many important markets are oligopolistic. In oligopolistic markets, many economists believe that firms often stress product improvement as a form of rivalry, rather than direct price competition. Because of tacit agreement among the firms, this may be the principal form of rivalry, with the result that more may be spent on research and development than is socially optimal. One industry in which this is sometimes claimed to be true is the ethical drug industry. This is not, however, a proposition that is easy to prove or disprove.

Despite the arguments listed above, another reason why there may be no under investment in various forms of civilian technology is that the government is already intervening in a large number of ways to support civilian technology. For example, as we saw in section 4, there are already some general tax incentives that encourage R. & D. Beyond this, in particular industries like aircraft, there are a host of government influences promoting R. & D. and technological change. For example, the Government has paid for R. & D. related to aircraft. It has increased the demand for new airplanes by providing subsidies to the airlines and by regulating the airlines in such a way as to discourage price competition. Of course, the aircraft industry is hardly typical in this regard, but, as we have seen, there is considerable government support for R. & D. of various kinds in the private sector, and it is not obvious, on *a priori* grounds, that the Government has not already offset whatever latent under investment in R. & D. that was present in particular parts of the economy.[16]

Going a step further, some economists have argued that, even in the absence of oligopoly or government intervention, a private enterprise economy might not under invest in R. & D. For example, it has been pointed out that the inventor might be in a position to predict and thus speculate on price changes resulting from the release of his new technology. In principle at least, this might offset the fact that he could not appropriate all of the benefits directly. But it is important to recognize how difficult it is to foretell what price changes will be, particularly since there are many factors other than the technology to be considered.[17]

In sum, there are several important factors, related to the inappropriability, uncertainty, and indivisibility of R. & D. that seem likely to push toward an under investment in R. & D. by the private sector. But these factors may be offset, partially or fully, by oligopolistic emphasis on nonprice competition, by existing government intervention, or by other considerations. Thus, on *a priori* grounds, it is impossible to say with any reasonable degree of certainty whether there is an under investment in R. & D. in particular parts of the private sector.

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[16] See Eads [8].
[17] See Hirshleifer [19].

6. Measurement of Social Benefits From New Technology: Agriculture

Since we cannot rely solely on *a priori* theorizing to tell use whether there is an under investment in R. & D. in the private sector (and if so, where it is most severe), we must turn to the available empirical studies of the returns from R. & D. of various types. These results should provide some information concerning what society has received from various forms of R. & D. investment in the past. Of course, there are a variety of problems in measuring the social benefits from new technology. Any innovation, particularly a major one, has effects on many firms and industries, and it obviously is difficult to evaluate each one and sum them up properly. Nonetheless, economists have devised techniques that should provide at least rough estimates of the social rate of return from particular innovations, assuming that the innovations can be regarded as basically resource-saving in nature.

To estimate the social benefits from an innovation, economists have used a model of the following sort. If the innovation results in a shift downward in the supply curve for a product (such as from S_1 to S_2 in figure 1), they have used the area under the product's demand curve (DD^1) between the two supply curves—that is, ABCE in figure 1—as a measure of the social benefit during the relevant time period from the innovation. If all other prices remain constant, this area equals the social value of the additional quantity of the product plus the social value of the resources saved as a consequence of the innovation. Thus, if one compares the stream of R. & D. inputs relating to the innovation with the stream of a social benefits measured in this way, it is possible to estimate the social rate of return from the R. & D. investment.[18]

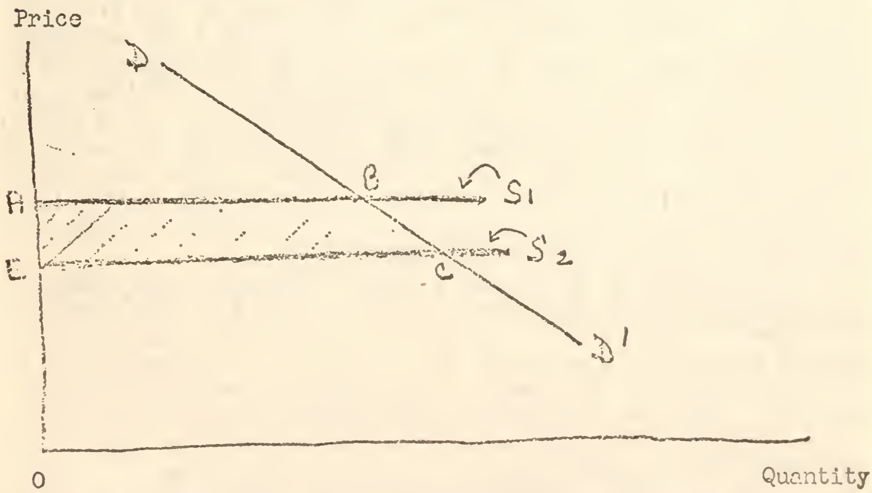

Figure 1.—Measurement of Social Benefits from Technological Innovation.

[18] See Mishan [36] and E. Mansfield, "Case Studies of the Measurement of Benefits from Scientific Information and Technological Innovation," presented at the First U.S.-U.S.S.R. Symposium on the Economics of Information, Leningrad, 1975.

One of the first studies to use this approach was Griliches's study of hybrid corn.[19] Based on data concerning the increase in yields resulting from hybrid corn, the value of corn output each year, and the price elasticity of demand for corn, he could estimate the area corresponding to ABCE in figure 1 each year. Then using data concerning the amount spent each year on hybrid corn research, he could estimate the rate of return from the investment in hybrid corn research, which turned out to be 37 percent. Clearly, a 37 percent rate of return is high. However, in evaluating this result, it is important to bear in mind, that this is the rate of return from an investment which was known in advance to have been very successful. Thus, it is not surprising that it is high.

Another study, based on much the same principles, was carried out by Peterson [20] to estimate the rate of return from poultry research. This study, unlike the previous one, looked at the rate of return from all research in this particular area, successful or not. In other words, it included the failures with the sucesses. The resulting rate of return was 18 percent, which again is a rather high figure. However, as would be expected, this figure is lower than that for hybrid corn. A further study, by Schmitz and Seckler, used basically the same kind of techniques to estimate the social rate of return from the investment in R. & D. pertaining to the tomato harvester. The result depends on how long workers displaced by the tomato harvester remained unemployed, but the authors report that, even if the tomato workers received compensation of $2 to $4 million per year for lost jobs, the net social rate of return from the harvester would still have far exceeded 100 percent.[21]

It is important to recognize that all of the rates of return cited so far are average rates of return. That is, they are the average rate of return from all of the amounts spent on the relevant R. & D. For many purposes, a more interesting measure is the marginal rate of return, which is the rate of return from an additional dollar spent. This is the measure that is most relevant in determining whether there is an under investment in civilian technology. If the marginal rate of return from investment in civilian technology is higher than the marginal rate of return from using the extra resources in other ways, more resources should be devoted to civilian technology. Thus, a very high marginal rate of return from investments in civilian technology is a signal of an under investment in civilian R. & D.

Using econometric techniques, a number of studies have estimated the marginal rate of return from agricultural R. & D. One study, by Griliches,[22] investigated the relationship in various years between output per farm in a state and the amount of land, labor, fertilizer, and machinery per farm, as well as average education and expenditures on research and extension in a State. The results indicate that, holding other inputs constant, output was related in a statistically significant way to the amount spent on research and extension. Assuming a 6-year lag between research input and its returns, these results indicate a marginal rate of return from agricultural R. & D. of 53

[19] See Griliches [14].
[20] See Peterson [53].
[21] See Schmitz and Seckler [57]. Since the concept of rate of return varies somewhat from study to study, the results are not always entirely comparable.
[22] See Griliches [15].

percent. Another study, by Evenson,[23] uses time-series data to estimate the marginal rate of return from agricultural R. & D., the result being 57 percent. Also, Peterson's study of poultry R. & D.[24] indicates that the marginal rate of return for this type of agricultural R. & D. is about 50 percent. Schultz's study indicates a marginal rate of return of 42 percent.[25]

In sum, every study carried out to date seems to indicate that the average social rate of return from agricultural R. & D. tends to be very high. The marginal social rate of return from agricultural R. & D. also seems to be high, generally in the neighborhood of 40 to 50 percent. Of course, as stressed above, these studies are based on a number of simplifications, and it would be very risky to attach too much significance to them, since they are rough at best. All that can be said is that the available evidence, for what it may be worth, suggests that the rate of return from agricultural R. & D. has been high.

7. Measurement of Social Benefits From New Technology: Industry

Having summarized the available results concerning the social rate of return from R. & D. in agriculture, we must now provide the same information for industry. Recently, a study was made by Mansfield, Rapoport, Romeo, Wagner, and Beardsley [26] of the returns from 17 specific industrial innovations. These innovations occurred in a variety of industries, including primary metals, machine tools, industrial controls, construction, drilling, paper, thread, heating equipment, electronics, chemicals, and household cleaners. They occurred in firms of quite different sizes. Most of them are of average or routine importance, not major breakthroughs. Although the sample cannot be regarded as randomly chosen, there is no obvious indication that it is biased toward very profitable innovations (socially or privately) or relatively unprofitable ones.

To obtain social rates of return from the investments in each of these innovations, my colleagues and I used a model somewhat like that described in figure 1, except that we extended the analysis to include the pricing behavior of the innovator, the effects on displaced products, and the costs of uncommercialized R. & D. and of R. & D. done outside the innovating organization. The results indicate that the median social rate of return from the investment in these innovations was 56 percent, a very high figure. On the other hand, the median private rate of return was 25 percent. (In interpreting the latter figure, it is important to note that these are before-tax returns and that innovation is a risky activity.)

In addition, my colleagues and I obtained very rich and detailed data concerning the returns from the innovative activities (from 1960 to 1972) of one of the Nation's largest firms. For each year, this firm has made a careful inventory of the technological innovations arising from its R. & D. and related activities, and it has made detailed estimates of the effect of each of these innovations on its profit stream. We

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[23] See Evenson [10].
[24] See Peterson [54].
[25] See Schultz [58].
[26] See [29]. Part of the relevant material will appear in E. Mansfield, J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley, "Social and Private Return from Industrial Innovations," *Quarterly Journal of Economics,* forthcoming issue.

computed the average rate of return from this firm's total investment in innovative activities during 1960–72, the result being 19 percent, which is not too different from the median private rate of return given in the previous paragraph. Also, we computed lower bounds for the social rate of return from the firm's investment, and found that they were about double its private rate of return, which also agrees with the results in the previous paragraph.

The foregoing results pertain to the average rate of return. In earlier investigations based on econometric estimation of production functions, Mansfield [27] and Minasian [28] estimated the marginal rate of return from R. & D. in the chemical and petroleum industries. Mansfield's results indicated that the marginal rate of return was about 40 percent or more in the petroleum industry, and about 30 percent in the chemical industry if technical change was capital embodied (but much less if it was disembodied). Minasian's results indicated about a 50 percent marginal rate of return on investment in R. & D. in the chemical industry.

In a more recent study, Terleckyj [29] has used econometric techniques to analyze the effects of R. & D. expenditures on productivity change in 33 manufacturing and nonmanufacturing industries during 1948–66. In manufacturing, the results seem to indicate about a 30 percent rate of return from an industry's R. & D. based only on the effects of an industry's R. & D. on its own productivity. In addition, his findings show a very substantial effect of an industry's R. & D. on productivity growth in other industries, resulting in a social rate of return greatly exceeding that of 30 percent. No evidence was found, however, demonstrating that government contract R. & D. has any effect on the productivity increase of the industries performing it.

Griliches [30] has carried out an econometric study, based on data for almost 900 firms, to estimate the rate of return from R. & D. in manufacturing. His results pertain only to the private, not the social, rate of return. He finds that the private rate of return is about 17 percent. It is much higher than this in chemicals and petroleum, and much lower than this in aircraft and electrical equipment. He finds that the returns from R. & D. seem to be lower in industries where much R. & D. is federally financed.

Based on computations for the economy as a whole, Denison concluded that the rate of return from R. & D. was about the same as the rate of return from investment in capital goods. His estimate of the returns from R. & D. was lower than the estimates of other investigators, perhaps due to his assumptions regarding lags.[31] In his presidential address to the American Economic Association, Fellner [32] estimated the average social rate of return from technological-progress activities, his conclusion being that it is "substantially in excess" of 13 or 18 percent, depending on the cost base, and that this is much higher than the marginal rate of return from physical investment at a more or less given level of knowledge.

To sum up, practically all of the studies carried out to date indicate that the average social rate of return from industrial R. & D. tends to

[27] See Mansfield [24].
[28] See Minasian [35].
[29] See Terleckyj [59].
[30] See Griliches [16].
[31] See Denison [7].
[32] See Fellner [11].

be very high. Moreover, the marginal social rate of return also seems high, generally in the neighborhood of 30–50 percent. As in the case of agriculture, there are a variety of very important problems and limitations inherent in each of these studies. Certainly, they are very frail reeds on which to base policy conclusions. But recognizing this fact, it nonetheless is remarkable that so many independent studies based on so many types of data result in so consistent a set of conclusions.

8. Mechanisms of Government Support in Other Countries

Having discussed the available evidence bearing on whether or not there may be an under-investment in civilian R. & D. of various kinds, we turn now to a brief description of some of the mechanisms used in three other countries—the United Kingdom, France, and Japan—to support R. & D. in the private sector.

United Kingdom

Like the United States, the United Kingdom has devoted a large share of its government R. & D. expenditures to defense and atomic energy (table 6). At the same time, however, it has tried in a variety of ways to support civilian technology as well. The National Research and Development Corporation is a public corporation that supports the development of innovations by paying part or all of the development costs, licenses firms to exploit public sector innovations, and enters into joint ventures with private firms. The British Government provides financial support for small firms, research associations, and universities to further the practical applications of research. Recently, the level of this support approximated $10 million per year. In 1970 it spent about $10 million to support research associations. In addition, it has engaged in large programs of grants to industry for research on processes, provided "launching aid" for the development of civilian aircraft and engines, and lent advanced machine tools without fee to potential purchasers or users.[32a]

Although it is difficult to evaluate programs of this sort, there seems to be a widespread feeling that Britain's programs have not been very successful. This is often attributed, at least in part, to the fact that the Government has been too inclined to assume the entrepreneurial role and to engage in commercial development activities. The Government has tended to commit itself to the full-scale development of particular technologies too soon and too massively. In other words, according to many experts in the United Kingdom and elsewhere, the British Government has tended to engage in activities that might better have been left to the private sector.[33]

France

There have been a number of French programs to support civilian technology, particularly in high technology fields or in fields thought to be important for industrial independence. There have been "thematic action programs," meant to coordinate applied work in inter-

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[32a] See Hollomon and Associates [20].
[33] See Gilpin [13].

disciplinary areas among several laboratories normally devoted to basic research. There have been "concerted actions," which establish committees to support research in fields like molecular biology and applied mechanics. There has been an "aid to pre-development" program, designed to help cooperative research organizations to development work on new technologies. There has been an "aid to development" program, providing loans (which may be forgiven) to cover development costs incurred by private firms.

Additionally, there are a variety of tax incentives. All of the operating expenses in research and development are fully deductible costs of doing business. Investments in buildings for R. & D. can be written off by 50 percent in the 1st year, the rest being depreciated over the structure's normal life. Firms that combine their R. & D. resources into a new organization can benefit from a tax deduction on their investment in the new organization. And to promote industrial funding of research institutions, there is a 50 percent depreciation rate for shares taken in public or private R. & D. institutions, deductions of payments to R. & D. institutions from profits taxes (up to 3 percent of the firm's turnover), and exemption of taxes on legacies to approved R. & D. institutions.[34]

In industries like electronics, French policy seems to have been to maintain at least one domestic supplier of each politically significant technology. In the eyes of many observers, this policy has had important drawbacks. According to Zysman:

> The dilemma has been that the protection and support required to produce specific products of interest to the state may, in fact, have weakened the firms that must be the long-term instruments of state policy . . . Before the reality of technological independence, strong and innovative firms, can be realized, the symbol of particular goods produced by subsidized but feeble national companies may have to be abandoned.[35]

Japan

There has been a well-known Japanese emphasis on the importation of technology. The Japanese Government has played a very important role in determining which technologies should be purchased from abroad, and which firms should receive them. Besides relying heavily on foreign technology, Japan has spent significant amounts on R. & D. As shown in table 7, Japan's R. & D. expenditures, as a percent of gross national product, have been lower than in the United States, United Kingdom, West Germany, or France. But if one looks only at nonmilitary R. & D., the gap between Japan's R. & D. expenditures, as a percent of gross national product, and that of the other countries is narrowed considerably. This, of course, is due to the fact that Japan spends very little on defense.

[34] See Hollomon and Associates [20].
[35] Zysman [63].

TABLE 6.—PERCENTAGE DISTRIBUTION OF PUBLIC RESEARCH AND DEVELOPMENT EXPENDITURES DEVOTED TO VARIOUS FUNCTIONS, 1968–69

Country	Military, space, nuclear	Economic, agriculture, manufacturing	Welfare, health, environment	Other, including universites	Total[1]
United States	79	6	13	2	100
Canada	29	49	11	11	100
Belgium	24	27	4	45	100
United Kingdom	59	22	4	15	100
Norway	17	40	8	35	100
Japan	9	25	4	62	100
Sweden	52	13	8	26	100
Netherlands	19	18	9	53	100
France	55	16	3	26	100

[1] Because of rounding errors, items sometimes do not sum to total.

Source: OECD statistics, as quoted in Gilpin [13].

TABLE 7.—RESEARCH AND DEVELOPMENT EXPENDITURES AS A PERCENTAGE OF GROSS NATIONAL PRODUCT, 1969.

Country	Total R. & D.	Nonmilitary R. & D.
United States	2.8	1.9
United Kingdom	2.2	1.7
Japan	1.5	1.5
France	1.9	1.6
West Germany	2.0	1.8

Source: Science and Technology Agency, Japan, as quoted by Peck [51].

An interesting feature of Japan's technology policy is that a very low percentage of the nation's R. & D. is financed by government. Japanese industry supports a much larger share of the nation's R. & D. than does industry in the United States, the United Kingdom, or France. About three-fifths of the Government's R. & D. expenditures on economic development are for the programs of the Agency of Industrial Science and Technology, which has run about a dozen national R. & D. programs on electronic computers, electric cars, sea water desalting, and other such topics. The projects are chosen on the basis of their potential importance to the economy. and the appearance of market failure which has prevented the private sector from carrying them out. Also, the Agency provides subsidies (amounting to one-half of the costs) for particular development projects proposed by industry. This program is smaller than the previously mentioned one, its total funding in 1972 approximating $9 million.

Japan also has used a variety of tax credits for industrial R. & D. In 1967, it introduced a program whereby a firm is permitted a 25 percent tax deduction on R. & D. expenses up to the point where they represent an increase of no more than 12 percent over the firm's highest annual R. & D. expenses since 1967, and a 50 percent tax deduction on additional R. & D. expenses, the maximum tax deduction being 10 percent of the corporate tax. Further, there is accelerated depreciation for the construction of pilot plants for new technology, accelerated de-

preciation for the building of R. & D. facilities and for startup expenses of research associations, and a partial tax exemption of receipts from foreign sale of technology.

Most observers seem to give high marks to Japan's programs in support of civilian technology. But it is difficult, particularly for outsiders, to characterize in a precise or detailed way the nature of some of these programs, since the Ministry of International Trade and Industry (MITI) has relied on informal guidance and intervention, as well as on formal controls, to influence the import of technology and the direction of civilian technology. However, one noteworthy feature of these programs is that they tended to view R. & D. as merely a part of the entire process of technological innovation, and that technological development has been viewed simultaneously with such other parts of the innovation process as investment, markets, and labor.[35a] These views coincide with the emphasis in many recent studies of the innovation process.

9. Advantages and Disadvantages of Various Mechanisms for Federal Support

As stressed in sections 5–7, existing evidence is too weak to indicate with any degree of certainty whether there is an underinvestment in civilian R. & D. of various sorts. All that can be said is that practically all of the studies carried out to date conclude that the average and marginal social rate of return from R. & D. have tended to be very high. Nonetheless, most economists who have studied the question [36] seem to feel, on the basis of the existing evidence, that it is likely that some underinvestment of this sort exists. If so, it is important to consider the various means by which Federal support for civilian R. & D. might be increased. In this section, we discuss the major advantages and disadvantages associated with each of a number of mechanisms for Federal support of private sector R. & D.

First, consider tax incentives for privately financed R. & D. Perhaps the most important advantages of this mechanism are that it involves less direct Government control than some of the other techniques, and that it would be relatively easy to administer. Its most important disadvantages are that it would reward firms for doing R. & D. that they would have done anyhow, that it would not help firms that have no profits, and that it would be likely to encourage the same kind of R. & D. that is already being done (rather than the more radical and risky work where the shortfall, if it exists, is likely to be greatest). Furthermore, according to estimates made by former Secretary Peterson of the Department of Commerce, a 25 percent tax credit for R. & D. would mean that the Treasury would lose about $2–3 billion annually.[37] Also, any program of this sort might run into difficulties in defining R. & D., since firms would have an incentive to use as wide a definition as possible. More will be said about tax credits in section 11.

Second, consider Federal contracts and grants in support of civilian technology. This, of course, is the route taken by the Department of Defense and the National Aeronautics and Space Administration in

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[35a] See Peck [51], Oshima [48], and Gilpin [13].
[36] See the papers in [41], Nelson, Peck, and Kalachek [45], Arrow [1], and Capron [4].
[37] See Weidenbaum [62].

much of their work. This is the route also taken by the National Research and Development Corporation in Britain and by some proposals in the United States.[38] It has the advantage of being direct and selective, but it can involve political problems in the choice of contractors, as well as problems relative to the disposition of patents resulting from such contracts and grants. At present, different Government agencies have adopted different policies with respect to patents. Some, notably the Department of Defense, allow the title to the patent to remain with the contractor; others, like the Atomic Energy Commission, have retained title to the patents. There has been a longstanding argument over the relative merits of these different patent policies.[39] Still another, more fundamental difficulty with this mechanism for supporting private sector R. & D. is that it is so difficult to estimate the social costs and benefits of a proposed R. & D. project in advance. More will be said about this in section 11.

Third, the Federal Government could support additional civilian R. & D. by initiating and expanding work of the relevant sorts in government laboratories. This technique has the advantage of being direct and selective. But there are great problems in having R. & D. conducted by organizations that are not in close touch with the marketing and production of the product. It is very important that there be unimpeded flows of information and good coordination of R. & D. on the one hand, and marketing and production, on the other. Otherwise, the R. & D. is likely to be misdirected, or even if it is not, it may be neglected or resisted by potential users. This is a difficult enough problem for various divisions of a firm, and it would seem to be made worse if the R. & D. is done in government laboratories. In the last decade, many governments have tended to convert government laboratories and to increase the amount of government-financed R. & D. done in industrial firms in order to bring R. & D. into closer contact with application and commercialization.[40]

Fourth, the Federal Government could insure a portion of private credit to firms for R. & D. and innovation costs. It is frequently claimed that the reluctance of lenders to extend credit to risky and long term projects is an undesirable barrier to innovation. To the extent that this is the case, such a program might help to remedy the situation. The government could, for a fee, share the risk with the private lender for loans for R. & D. and related purposes. The advantages of such a program are that it would not commit the government to large expenditures, the administrative costs would be low, and there would be little federal interference in the lending decision. The disadvantages are that it results in a contingent liability for the Treasury, political problems could arise in awarding the loan insurance, and, most important of all, there is very little hard evidence that the capital markets operate so inefficiently (from a social point of view) that such a program is needed.[41]

Fifth, the Federal Government could use its own purchasing procedures to encourage technological change in the private sector. As shown in table 8, the Federal Government's purchases of many kinds

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[38] See Nelson, Peck, and Kalachek [45].
[39] See Mansfield [25].
[40] See OECD [47].
[41] See Pickarz [55].

of goods and services are very substantial. The Federal Government could encourage innovation by using performance criteria, which specify the desired end result without limiting the design to existing products, rather than product specifications. Proponents of performance-based Federal procurement argue that it will free industry to innovate (limited only by the requirement that it perform certain specified functions), encourage cost reduction for the Government, and encourage the Government to serve as a pilot customer for technical innovations in areas where it represents a big enough market or a market sufficiently free from local restrictions or codes to make it worth industry's while to innovate. The disadvantages of this mechanism are that performance criteria may be expensive to develop and administer, and that the procurement process may be made less efficient by adding innovation to the list of socioeconomic objectives that already influence this process.[42] Another suggestion is that the Government could make greater use of life cycle costs in purchasing decisions.

TABLE 8.—*Government sales as a percent of total sales, 1967*

Product line	*Percent sold to Federal Government*
Food and kindred products	1.86
Tobacco manufactures	3.53
Textile mill products	1.13
Lumber and wood products	0.96
Furniture and fixtures	1.99
Paper and allied products	0.82
Chemicals and allied products	1.53
Petroleum and coal products	1.45
Rubber and miscellaneous plastics products	2.57
Leather and leather goods	4.19
Stone, clay, and glass products	0.83
Primary metal industries	1.08
Fabricated metal products	3.20
Machinery except electrical	3.39
Electrical machinery and supplies	14.05
Transportation equipment	28.01
Instruments	11.05
Miscellaneous manufacturing	1.97
Wholesale trade	1.60

Source: Study Group 13A on Commercial Products, *Final Report to the Commission on Government Procurement,* Washington, February 1972, p. 42.

Sixth, the Federal Government could use its regulatory policies to try to encourage R. & D. in the private sector. According to some observers, some (but by no means all) of the Federal regulatory agencies have, through their policies and procedures, tended to restrain or distort technological innovation in the industries they regulate.[43] Because so little is known about the effects of regulation on technological change, it is hard to specify exactly what changes might be effective (and cost-effective). Among the suggested alternatives are that technology advisers be located in the regulatory agencies, and that a technology impact statement be appended to all major regulatory decisions. Based on existing knowledge, it is hard to say whether such actions would be worthwhile.[44]

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[42] See Davenny [6] and Weidenbaum [62].

[43] For example, former President Nixon, in his 1972 message on science and technology, cited excessive regulation as a barrier to innovation in the United States.

[44] See Mogee [37] and Eads [8].

Seventh, the Federal Government might establish prizes for important industrial innovations and developments. Such prizes would of course, make privately financed R. & D. more attractive: if a firm or individual felt that a prospective R. & D. project might lead to results worthy of such a prize, the rewards would appear higher than without the prize. An important disadvantage of this mechanism is that it is so difficult to figure out which innovations are worthy of prizes and which are not. Given the enormous problems in measuring the social importance of an innovation, this mechanism may not be as feasible as might appear at first glance.

10. Three Federal Programs Designed To Illuminate the Issues

On March 16, 1972, former President Nixon, in his special message to the Congress on science and technology, established three programs related to Federal support of R. & D. in the private sector. One was to be an analytical program at the National Science Foundation to support studies of barriers to technological innovation and the effects of various possible Federal policies on these barriers. The other two, one to be carried out at the National Science Foundation and one at the National Bureau of Standards, were to be experimental programs to determine effective ways of stimulating R. & D. in the private sector and to provide experience with incentives that the Federal Government might use to promote the application of science and technology in the civilian sector. In this section, we describe the nature and status (as of 1975) of these programs, each of which has an obvious bearing on the topic of this report.

The National Science Foundation's National R. & D. Assessment Program

Established in August 1972, this is the analytical program cited above. This program analyzes the patterns of R. & D. and technological innovation in the United States, the incentives and decisions that underlie these patterns, and the effects of various Federal policy options on future patterns of R. & D. and technological innovation in this country. More specifically, this program attempts to shed light on the following sorts of questions: How are decisions made with regard to R. & D. and technological innovation? How does government regulation affect R. & D. and technological innovation? How do tax policies, patent policies, and antitrust policies affect R. & D. and technological innovation? What are the social benefits and costs from technological innovations? What are the effects of international technology transfer on U.S. balance of trade and employment?

To carry out its work, the National R. & D. Assessment Program supports both intramural and extramural work. A great many of the extramural projects have yet to reach completion, since most of them were not begun until fiscal 1974. Thus, it is too soon to attempt to summarize the results obtained to date. However, it is clear that this program will add to the stock of fundamental knowledge in this area. For example, some of the works cited earlier in this paper were supported by this program. It is to be hoped that a number of the issues considered in this report will be clarified considerably by the results to be obtained by this program.

The National Science Foundation's Experimental Research and Development Incentives Program

This includes a number of experimental programs. Among other things, it has made federal laboratories available for performance validation in cases where an entrepreneur obtains a conditional commitment to buy from a public jurisdiction, it has made university research capabilities available to several industrial sectors not currently doing much R. & D. it has established interdisciplinary training and community clinics at several universities for the development of entrepreneurial talent and the planning of innovations, it has experimented with the use of a structured national system to deliver technical services to small and medium sized cities through the use of a technology agent, and it has established a training program and organized procedure for obtaining clinical validation of new medical equipment.

Like the other programs discussed in this section, too little time has elapsed to be able to say much concerning the nature of the results. However, one thing that this program has demonstrated is the difficulty of establishing experiments that are feasible and susceptible to precise evaluation. To formulate an experiment that can shed unambiguous light on any of the relevant questions is not as easy as it may seem. To do this, and at the same time remain within the bounds of political and economic feasibility, is harder still. Nonetheless, it is to be hoped that, when they become available, the results will clarify a number of the issues considered in this report.

The National Bureau of Standards' Experimental Technology Incentives Program

This experimental program was started in 1972, but for various reasons it was not until September 1973 that a full-time director was present, and operating funds were not available until February 1974. This program has focused its attention largely on federal procurement and regulation. In the area of federal procurement, it is working with the Federal Supply Service to introduce life cycle costing and value incentive clauses in the procurement of power mowers, air conditioners, hot water heaters, and a variety of other products. Also, it is working with the Public Building Service in the development of a life cycle costing methodology for use in planning and acquiring federal space, and with the Veterans Administration and the state and local governments in experiments involving performance specifications and other procurement changes. In the area of federal regulation, it is working with the Nuclear Regulatory Commission to see whether the formulation of standards can be expedited, with the Environmental Protection Agency to see whether it is possible to reduce the high costs of complying with regulations concerning the development of pesticides, with the Federal Power Commission and the Occupational Safety and Health Administration to experiment with the use of computers and modern information handling technology, and with the Federal Rail Commission and Food and Drug Administration on other problems. Finally, it is also engaged in some studies of civilian R. & D. and of ways to encourage innovation by small business.

According to the program officials, the results to date are encouraging. For example, they estimate that the use of life cycle cost

methods has resulted in a saving to the government of $400,000 in the case of air conditioners and of $300,000 in the case of water heaters purchased in one year alone. Relatively straightforward changes in the nuclear standards formulation process seem to have expedited this process considerably. With regard to the encouragement of innovation in the private sector, the program's officials feel that progress has been made. As in the case of the Experimental Research and Development Incentives Program, it is very difficult at this point to say what the net effect of each of these experiments has been and to tell whether they will result in social benefits exceeding their social costs. Nonetheless, it seems reasonable to expect that this program will shed light on a number of the major issues considered in this report.[45]

11. General Versus Selective Support Mechanisms

In section 8, we described briefly some of the mechanisms used by the governments of Britain, France, and Japan to support R. & D. in the private sector. In section 9, we discussed the advantages and disadvantages of various mechanisms that could be used in the United States to increase Federal support of private-sector R. & D., if this were deemed desirable. In section 10, we described several programs currently being carried out by government agencies which should shed light on the relative desirability of some of these mechanisms, as well as on the desirability of further Federal support for private sector R. & D. With this material as background, we turn now to a discussion of some of the major considerations that probably should be kept in mind in appraising the policy options in this area.

To begin with, it seems fair to say that most economists who have studied this problem have come away with the impression that our nation's programs in support of civilian technology are *ad hoc*, and that it is difficult to understand why we have allocated this support in the way that we have. For example, an enormous amount of support has been provided for civilian aviation technology, but very little has been provided for railroad technology; an enormous amount of support has been provided for agricultural technology, but very little has been provided for construction technology; and so on. (Perhaps this allocation of support can be defended, but I know of no serious attempt to do so.) Also, many economists who have written on this topic seem somewhat uncomfortable about the extent to which federal support of R. & D. in the private sector is related to a relatively few high technology areas. When one looks at federal expenditures for R. & D. performed in the private sector, the data, shown in Table 4, indicate that the lion's share goes to industries like aircraft, electrical equipment, and instruments. Yet the marginal rate of return from R. & D. may be higher in less exotic areas like textiles or machine tools than in these high-technology fields.

If these misgivings are close to correct, it is likely that a general tax credit for R. & D. would be a relatively inefficient way of increasing federal support for R. & D. in the private sector. This is because, as pointed out in section 9, it would reward many firms for doing what they would have done anyway, and it would be likely to encourage the same sorts of R. & D. that are already being done. A tax credit for

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[45] For some recent discussion of this program, see Science, September 26, 1975.

increases in R. & D. spending would be less objectionable on these grounds, but it too is frequently regarded as inefficient because it is not sufficiently selective. To get the most impact from a certain level of Federal support, it seems to be generally agreed that a more selective technique would be desirable.

However, to utilize more selective techniques, some way must be found to determine where the social payoff from additional federal support is greatest (or at least relatively high). The way that most economists would approach this problem is to use some form of benefit-cost analysis to evaluate the pay-off from additional Federal support of various kinds of R. & D. Unfortunately, although such methods are of some use, they are not able to provide very dependable guidance as to how additional Federal support for civilian technology should be allocated, due in large part to the fact that the benefits and costs from various kinds of R. & D. are very hard to forecast. As the Department of Defense knows so well, it is difficult indeed to forecast R. & D. costs. And even major corporations have difficulty in using various forms of benefit-cost analysis for R. & D. project selection, even though they have a much easier benefit concept to estimate than most Government agencies do.

Thus, the choice between the general and more selective forms of support is not as simple as it may seem at first. And when one recognizes that the estimates constructed to guide the selective forms of support may be biased for parochial, selfish, or political reasons, the choice becomes even more difficult. As Eads [46] has pointed out, the organizations and individuals that benefit from, or have a positive interest in, a certain R. & D. program may inflate the benefits estimate by claiming various "secondary" or "external" benefits that in fact are spurious or at least exaggerated. Given that it is so hard to estimate with reasonable accuracy the true social benefits of various R. & D. programs, the result could be a distortion of social priorities, if the estimates are taken seriously. And if they are not taken seriously, it would be difficult to prove them wrong.

Another consideration also bears on this choice. As noted in section 7, some studies have concluded that an industry's R. & D. expenditures have a significant effect on its rate of productivity increase, but that the amount of federally financed R. & D. performed by an industry seems to have little or no such effect. In part, this may be due to the possibility that output measures in industries like aircraft are not reliable measures of social value. But it may also be due to a difference in the effectiveness of federally financed and privately financed R. & D. At present, there is no way to tell how much of the observed difference is due to the latter effect; but if it turns out to be substantial, this would seem to favor tax credits rather than increased Federal contracts and grants.[47]

To sum up, although selective forms of support have obvious advantages (where they are at all appropriate), it would seem that they might well be supplemented with more general forms of support. Tax credits for increases in R. & D. spending are less objectionable than a tax credit for R. & D. spending. Although there are problems in de-

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[46] See Eads [8].
[47] For an argument favoring the use of tax credits for increments in R. & D. expenditures, see Boretsky [3].

fining R. & D. (and thus in measuring increases in R. & D. expenditures), a tax credit for increases in R. & D. spending might be considered, if it seems desirable to increase federal support for civilian technology. If adequate measures were available to guide more selective forms of support, perhaps they alone could do the job; but such measures are presently in their infancy.

12. Major Considerations in Formulating Programs

The choice of the general type (or types) of program is only one of many decisions that would have to be made, if some new federal support for R. & D. in the private sector were deemed desirable. This section takes up five additional points concerning the formulation of such a program. First, to the extent that such a program were selective, there seems to be a considerable amount of agreement among economists that it should be neither large scale nor organized on a crash basis. Instead, it should be characterized by flexibility, small-scale probes, and parallel approaches. In view of the relatively small amount of information that is available and the great uncertainties involved, it should be organized, at least in part, to provide information concerning the returns from a larger program. On the basis of the information that results, a more informed judgment can be made concerning the desirability of increased or, for that matter, perhaps decreased amounts of support.[48]

Second, any temptation to focus the program on economically beleaguered industries should be rejected. The fact that an industry is in trouble, or that it is declining, or that it has difficulty competing with foreign firms is, by itself, no justification for additional R. & D. More R. & D. may not have much payoff there, or even if it does, the additional resources may have a bigger payoff somewhere else in the economy. It is important to recall the circumstances under which the government is justified in augmenting private R. & D. Practically all economists would agree that such augmentation is justifiable if the private costs and benefits derived from R. & D. do not adequately reflect the social costs and benefits. But in many industries there is little or no evidence of a serious discrepancy of this sort between private and social costs and benefits. Indeed, some industries may spend too much, from society's point of view, on R. & D.

Third, except in the most unusual circumstances, the government should avoid getting involved in the latter stages of development work. In general, this is an area where firms are far more adept than government agencies. As Pavitt has put it, government programs in support of civilian technology "should be managed on an incremental, step-by-step basis, with the purpose of reducing key scientific and technical uncertainties to a degree that private firms can use the resulting knowledge to decide when (with their own money) they should move into full-scale commercial development.[49] "Although there may be cases where development costs are so high that private industry cannot obtain the necessary resources, or where it is so important to our national security or well-being that a particular technology be developed that the government must step in, these cases do not arise very often. In-

[48] Some of the material in this and the next section closely parallels parts of [27].
[49] Pavitt [49], p. 16.

stead, the available evidence seems to indicate that, when governments become involved in what is essentially commercial development, they are not very successful at it.[50]

Fourth, in any selective government program to increase support for civilian technology, it is vitally important that a proper coupling occur between technology and the market. Recent studies of industrial innovations point repeatedly to the key importance of this coupling. In choosing areas and projects for support, the government should be sensitive to market demand. To the extent that it is feasible, potential users of new technology should play a role in project selection. Information transfer and communication between the generators of new technology and the potential users of new technology are essential if new technology is to be successfully applied. As evidence of their importance, studies show that a sound coupling of technology and marketing is one of the characteristics that is most significant in distinguishing firms that are relatively successful innovators from those that are relatively unsuccessful innovators.[51]

Fifth, in formulating any such program, it is important to recognize the advantages of pluralism and decentralized decisionmaking. If the experience of the last 25 years in defense R. & D. and elsewhere has taught us anything, it has taught us how difficult it is to plan technological development. Technological change, particularly of a major or radical sort, is marked by great uncertainty. It is difficult to predict which of a number of alternative projects will turn out best. Very important concepts and ideas come from unexpected sources. It would be a mistake for a program of this sort to rely too heavily on centralized planning. Moreover, it would be a mistake if the government attempted to carry out work that private industry can do better or more efficiently.

13. Technological Change and Antitrust Policy

Besides the considerations discussed in previous sections, it is important to point out that our general economic policies may have a notable impact on R. & D. and technological change in the private sector. Like other economic variables, the rate of technological change is influenced by the general economic climate or environment, which in turn is influenced by our general economic policies. Thus, our policies regarding market structure, competition, unemployment, inflation, foreign trade, and a host of other economic matters are important in this regard. In this section of this paper, we take up the effects of one aspect of our general economic policy, namely, our antitrust policies.

There has been a considerable amount written by economists concerning the effects of market structure and antitrust policy on the rate of technological change. Although we are far from having final or complete answers, the following generalizations seem warranted, based on the available evidence.

First, the role of the small firm is very important at the stage of invention and the initial, relatively inexpensive stages of R. & D. Studies by Jewkes, Sawers, and Stillerman, Hamberg, Mueller, and

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[50] See Eads and Nelson [9]. Pavitt [49] reports that, according to a recent study by Gardner, the British government since the Second World War has recovered less than one-tenth of its outlays on launching aid for aircraft and aircraft engines.
[51] See Freeman [12], Mansfield, Rapoport, Schnee, Wagner, and Hamburger [28], and Mansfield, Rapoport, Romeo, Villani, Wagner and Husic [29].

others[52] indicate that small firms and independent inventors play a large, perhaps a disproportionately large, role in conceiving major new ideas and important inventions. Further, although full-scale development often requires more resources than small firms command, the investment required for development and innovation is seldom so great or so risky that only the largest firms in an industry can do the innovating or the developing. Studies of the drug, coal, petroleum, and steel industries indicate that, in all of these industries, the firms that carried out the most innovations, relative to their size, were not the biggest firms.[53] Only in the chemical industry does it appear that the largest firm has done the most innovating relative to its size.[54]

The available evidence does not seem to indicate that giant firms devote more resources, relative to their size, to inventive and innovative activities than their somewhat smaller competitors. There seems to be a threshold effect. A firm has to be a certain size to spend much on R. & D. (as defined by the National Science Foundation), but beyond a certain point, increases in size no longer bring a proportionate increase in R. & D. expenditures.[55] As would be expected, the threshold varies from industry to industry, but it appears that increases in size beyond an employment level of about 5,000 employees generally do not result in more than proportional increases in innovation inputs or outputs. Moreover, there is some evidence that the biggest firms produce less inventive and innovative output, per dollar of R. & D., than smaller firms.

Turning from size of firm to industrial concentration (which can be quite a different thing), most studies of the relationship between industrial concentration and the rate of technological change conclude that a slight amount of concentration may promote more rapid invention and innovation. For example, very splintered, fragmented industries like construction do not seem to be able to promote a rapid rate of technological advance. But beyond a moderate amount of concentration, further increases in concentration do not appear to be associated with more rapid rates of technological advance. Thus, the evidence does not seem to indicate that very great concentration must be permitted to promote rapid technological change and the rapid adoption of new technologies.[56]

Several other points should be noted. First, new firms and firms entering new markets play a very important role in the process of technological change. Existing firms can be surprisingly impervious to new ideas, and one way that their mistakes and inertia can be overcome in our economy is through the entry of new firms. Second, cases sometimes occur where industries contain such small firms or markets are so fragmented that technological change is hampered. In such cases, as we pointed out in section 2 (in connection with agriculture), it may be good public policy to supplement the R. & D. provided by the private sector. Third, it is generally agreed by economists that the ideal market structure from the point of view of promoting technological change is one characterized by a mixture of firm sizes. Com-

[52] See Jewkes, Sawers, and Stillerman [21], Hamburg [18], Mueller [38], and Scherer [56].
[53] See Mansfield [26] and Mansfield et al. [28].
[54] See Mansfield et al. [29].
[55] See Scherer [56]. An exception here is the chemical industry.
[56] See Scherer [56].

plementarities or interdependencies exist among firms of various sizes. There is often a division of labor, smaller firms focusing on areas requiring sophistication and flexibility and catering to specialized needs, bigger firms focusing on areas requiring larger production, marketing, or technological resources.

To sum up, the available evidence does not indicate that we must permit very great concentration of American industry in order to achieve rapid technological change and the rapid adoption of new techniques. Instead, it seems to suggest that public policy should try to eliminate unnecessary barriers to entry and to promote competition in American industry. At the same time, it is worth noting that the effects of the antitrust laws are not unmixed. For example, the antitrust laws may reduce the incentives of the dominant firm (or firms) in an industry to innovate.

14. Summary and Conclusions

In conclusion, the federal government supports R. & D. in the private sector in a variety of ways. In 1974, the federal government financed about $8 billion of R. & D. carried out by firms, about $3 billion of R. & D. carried out by colleges and universities, and about $1 billion of R. & D. carried out by other nonprofit organizations. (Of course, some recipients, such as State universities, are not in the private sector.) Much of the R. & D. performed by the private sector for the federal government is directed toward technological change in public goods like defense and space exploration, not toward private-sector problems. The rationale for federally financed R. & D. directed at private sector problems is generally that the private costs and benefits from R. & D. do not adequately reflect the social costs and benefits. Besides its contracts and grants, the federal government also supports and encourages private-sector R. & D. through the patent laws, the tax laws, some aspects of regulation, the antitrust laws, federal programs to transfer technology, and its educational policies. There is no way to put an accurate dollar figure on the amount of support from these activities.

Due to the inappropriability, uncertainty, and indivisibility of R. & D., an under-investment in R. & D. may occur in the private sector. But this may be offset, partially or fully, by oligopolistic emphasis on nonprice competition, by existing government intervention, or by other considerations. Based on simple models, economists have attempted to estimate social rates of return from various kinds of investments in R. & D. and technological innovation, both in agriculture and industry. The results seem to suggest that both the marginal and average social rates of return have been very high, and many economists have interpreted these results as evidence of a possible under-investment in R. & D. However, these estimates suffer from many important limitations, and should be viewed with caution.

There are a variety of ways that the government might stimulate additional R. & D. in the private sector—tax credits, R. & D. contracts and grants, expanded work in government laboratories, loan insurance for innovation, purchasing policies with greater emphasis on performance criteria and life cycle costing, altered regulatory policies, and prizes. An important problem with a general tax credit is its in-

efficiency; an important advantage is that it involves less direct government controls. An important problem with more selective support mechanisms is that it is so difficult to estimate in advance the social benefits and costs of particular types of R. & D. projects. In my own opinion, if a program of this sort were started, a combination of selective and more general forms of support would be most effective.

Although many economists suspect that there may be an underinvestment in certain areas of civilian technology, there is at the same time some concern that the federal government, in trying to improve matters, could do more harm than good. In this regard, it seems to be generally agreed that any selective program should be neither large-scale nor organized on a crash basis, that it should not be focused on helping beleaguered industries, that it should not get the government involved in the latter stages of development work, that a proper coupling be maintained between technology and the market, and that the advantages of pluralism and decentralized decision-making be recognized.

In previous sections of this paper, I have discussed (all too briefly) a variety of policy alternatives that have been suggested for improving the existing federal posture concerning civilian technology, as well as the broad issues that bear on the relative desirability of many of these policy alternatives. Perhaps the most important point to emphasize in this connection is the extent of our ignorance and uncertainty. There sometimes is a tendency to slur over—or perhaps not to recognize—the fact that very little really is known concerning the effects of many of these policy alternatives, or concerning the desirability of their effects. (Indeed, in some areas, no one really knows how to study these questions effectively, let alone provide answers here and now.) Given the current uncertainties, it would seem wise to proceed with considerable caution, and to build into any program the capacity and necessity to resolve many of the key uncertainties before too big a commitment is made.

Finally, it is important to recognize that the nation's basic economic policies may have a notable impact on R. & D. and technological change in the private sector. Technology policy, after all, must be integrated with and viewed in the context of, our overall economic policy. With regard to antitrust policy, which is an important element of our basic economic policy, the available evidence does not indicate that we must permit very great concentration of American industry to achieve rapid technological change and the rapid adoption of new techniques.

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